Digitized by the Internet Archive
in 2013

http://archive.org/details/geologyfromorigi00will

GEOLOGY FROM ORIGINAL SOURCES

Photo © Hileman, Kalispell, Mont.

DIAMOND FALLS AND MOUNT JACKSON, GLACIER NATIONAL PARK, MONTANA. THE WATER FALLS MORE THAN 1,300 FEET.

GEOLOGY FROM ORIGINAL SOURCES

ORGANIZED COLLATERAL READINGS FOR STUDENTS IN GENERAL GEOLOGY

Compiled and arranged by

WILLIAM M. AGAR
ASSISTANT PROFESSOR OF GEOLOGY IN COLUMBIA UNIVERSITY

RICHARD FOSTER FLINT
ASSISTANT PROFESSOR OF GEOLOGY IN YALE UNIVERSITY

AND

CHESTER R. LONGWELL
HENRY BARNARD DAVIS PROFESSOR OF GEOLOGY IN YALE UNIVERSITY

NEW YORK
HENRY HOLT AND COMPANY

COPYRIGHT, 1929,
BY
HENRY HOLT AND COMPANY, INC.

PRINTED IN THE
UNITED STATES OF AMERICA

PREFACE

THE modern textbook in General Geology presents a mass of facts, terms, and definitions, and succeeds more or less in making clear the relationships between the facts presented. This systematic treatment, involving the pointing out of relationships, represents a marked advance over the textbooks of an earlier generation; but still the keen, intelligent student is not satisfied. He is not content with the attempt to derive nourishment, bone by bone, from the bare skeleton of the subject. He wants the framework covered with succulent flesh, and one can scarcely blame him. Some of the facts of Geology are impressive, some of them even astonishing, to the beginner. But the gaunt structure of the facts is far more pleasing when it is filled in and rounded out with material that while basically less essential is nevertheless important as regards the making of a human and vital study of Geology. After all, there is much to be learned about what has been well said, about what has been well reasoned, and about the circumstances under which some of the more important discoveries in Geology were made. These are the things that lend reality and romance to the study, and that help the student to appreciate the virility of Geology and to realize that the great geologists were human beings with vitality of expression as well as of thought.

It seems desirable, therefore, in a course of college grade, that the text used should be supplemented by the kind of collateral reading which is capable of supplying this need. There is an adequate literature in Geology, some parts of which are richly rewarding. It would not be difficult to refer the student to many excellent original works. But this would be practicable only in an institution with few students and an extensive and varied library in Geology. For the large groups of students such as are characteristic in most modern courses in General Geology, the library plan is out of the question. A book that presents selections from the best literature on the various subjects treated in Geology offers the readiest solution to the problem.

In their teaching experience the compilers of the present volume have felt keenly this want of suitable collateral material, available in a convenient form. The material that follows has been gradually collected, tested, and rearranged through use in the compilers' classes. Selections have been made on a basis of (1) interest inherent in the subject, (2) readability, (3) conciseness, and (4) (unfortunately) availability of the material for reproduction. The extracts have been grouped into chapters covering the broader subdivisions of the subject, but no attempt has been made to insure completeness to any chapter. The chapters appear in the general order of those in Pirsson and Schuchert's "Textbook of Geology," Part I (Third Edition, 1929); but the extracts are so arranged that they can be used with any standard text. The material is not cumulative; it is flexibly arranged so that readings may be assigned in any order desired.

The material that follows has been collected, annotated, and arranged by the compilers on a basis of strict equality of cooperation. The order in which the compilers' names appear on the title-page is entirely arbitrary. Direct responsibility for the chapters is allocated as follows: Chapters I, II, V, XII, XIV, Agar; Chapters III, IV, VI, XIII, XV, Flint; Chapters VII, VIII, IX, X, XI, Longwell. Each chapter has, however, been contributed to and critically revised by all three compilers.

It is hoped that these selections from geologic literature may serve to illuminate further the subjects treated in the classroom, and to guide the student to original sources from which he may derive not only additional knowledge but enjoyment as well.

New Haven,
March, 1929.

ACKNOWLEDGMENTS

The following publishers have generously permitted the use of copyrighted material from the books indicated:

American Geographical Society:
  Isaiah Bowman, *Desert trails of Atacama.* 1924.
  D. W. Johnson, *Battlefields of the world war.* 1921.
American Museum of Natural History:
  H. P. Whitlock, *The story of the minerals.* 1925.
R. V. Coleman, National Book Buyers' Service:
  C. E. P. Brooks, *The evolution of climate.* 1922.
R. R. Donnelley and Sons Company:
  William L. Manly, *Death Valley in '49.* 1927.
Harper and Brothers:
  Samuel L. Clemens (Mark Twain), *Life on the Mississippi.* 1874.
Ellsworth Huntington:
  Ellsworth Huntington: *The pulse of Asia.* Houghton Mifflin Co. 1907.
Kegan Paul, Trench, Trubner and Company, Ltd.:
  A. E. H. Tutton, *The natural history of ice and snow.* 1927.
Lea and Febiger:
  Sir Henry T. De la Beche: *The geological observer.* Blanchard and Lea. 1851.
McGraw-Hill Book Company:
  Kraus & Holden, *Gems and gem materials.* 1925.
  Charles H. Shamel, *Mining, mineral, and geological law.* Hill Book Co. 1907.
Methuen and Company, Ltd.:
  S. Baring-Gould, *The deserts of southern France.* 1894.
John Murray:
  J. W. Gregory, *The nature and origin of fiords.* 1913.
National Geographic Society:
  Powell, Willis, et al., *Physiography of the United States.* 1896.
Payot:
  D. W. Johnson, *Paysages et problèmes géographiques de la terre américaine.* 1927.

Charles Scribner's Sons:
    John C. Van Dyke, *The desert.* 1901.
The Macmillan Company:
    Sir Archibald Geikie, *The founders of geology.* 1905.
    George P. Merrill, *A treatise on rocks, rock weathering and soils.* 1904.
The Republic Publishing Company:
    The New Republic, May 18, 1927.
The Scientific Monthly, vol. 27, 1928.
The Technology Review, vol. 30, 1927.
The University of Chicago Press:
    W. D. Jones and D. S. Whittlesey, *An introduction to economic geography.* 1925.
D. Van Nostrand Company:
    Milton Whitney, *Soil and civilization.* 1925.
Yale University Press:
    Herbert E. Gregory, *Military geology and topography.* 1918.

For permission to reproduce illustrations, we are indebted to the following:

American Geographical Society, New York.
Geological Survey of England and Wales, London.
Hawaiian Volcano Observatory, Hawaii.
Mississippi River Commission, St. Louis.
National Geographic Society, Washington.
New Zealand Government Publicity Bureau.
U. S. Army Air Corps, Washington.
U. S. Coast and Geodetic Survey, Washington.
U. S. Geological Survey, Washington.
Vermont Marble Company, Proctor, Vt.

Mr. Hugh H. Bennett.
Dr. Eliot Blackwelder.
Mr. R. V. Davis.
Mr. John R. Freeman.
Mr. R. E. Fuller.
Mr. M. Fuyura.
Mr. Oliver J. Grimes.
Mr. T. J. Hileman.
Professor D. W. Johnson.
Professor Adolph Knopf.

Mr. Tai Sing Loo.
Mr. François Matthes.
Mr. R. W. Mattoon, U. S. Forest Service.
Mr. W. C. Mendenhall.

Nearly all of the aerial photographs were generously furnished by the U. S. Army Air Corps in order to show geologic features that appear to best advantage in photographs taken from the air. Pictures of the subjects shown were unobtainable save through the courtesy of the Air Corps.

EXPLANATORY NOTE ON THE REFERENCES

It has seemed advisable to adopt a simple and uniform system of references to the source-material quoted. The author and general subject of each excerpt are cited in the table of contents. A full citation of each source quoted appears, in alphabetical arrangement, in a bibliography at the end of every chapter. In the paragraphs introducing the various excerpts appear brief citations in parenthesis, thus: (Lyell, 1853, pp. 61-72). These refer to the longer citations in the bibliographies at the ends of the respective chapters. Footnotes are used only where they appear incorporated in a quoted source-passage, and where the meaning of some quoted phrase or term needs clarification.

CONTENTS

CHAPTER PAGE

I. MINERALS AND ROCKS 3

MINERALS (*Kraus and Holden*) 3

The substance of the Earth (*H. P. Whitlock*) . 4

Crystals (*H. P. Whitlock*) 5

Crystalline structure (*H. P. Whitlock*) . . . 9

Gems (*Kraus and Holden*) 10

The naming of gems (*Kraus and Holden*) . . 12

Artificial and imitation gems (*Kraus and Holden*) 14

The uses of minerals (*Jones and Whittlesey*) . 20

ROCKS 22

Sir James Hall's experiments (*Sir Archibald Geikie*) 23

Practical uses of rocks (*Jones and Whittlesey*) . 26

Building stone (*Jones and Whittlesey*) . . . 27

Mineral building materials other than stone (*Jones and Whittlesey*) 28

II. CLIMATE, WEATHERING AND SOILS 30

CLIMATE 30

Rainfall of the desert (*Isaiah Bowman*) . . 31

Exceptional rains and floods in the Nitrate Desert (*Isaiah Bowman*) 32

The desert of Tarapacá (*Isaiah Bowman*) . . 32

Evidence for climatic changes (*Albrecht Penck*) . 34

Recent climatic changes (*C. E. P. Brooks*) . . 39

The evidence from Asia (*Ellsworth Huntington*) . 43

The dry river and the dry mountains (*Ellsworth Huntington*) 46

The waxing and waning of Lop-Nor (*Ellsworth Huntington*) 47

The Caspian Sea and its neighbors (*Ellsworth Huntington*) 51

WEATHERING AND SOILS 53

The instability of minerals (*George P. Merrill*) . 53

Subaërial decay of rocks (*I. C. Russell*) . . 56

Decay of the crystalline rocks of the Piedmont region (*I. C. Russell*) 56

Decay of the rocks of the Newark system (*I. C. Russell*) 58

Absence of decayed rocks in the Far West (*I. C. Russell*) 60

The organization of the soil (*Milton Whitney*) . 64

CHAPTER PAGE

III. STREAMS AND VALLEYS 68
- Early ideas concerning streams 68
- Origin of valleys (*John Playfair, William Buckland, Edward Hitchcock*) 68
- Analysis of erosion (*G. K. Gilbert, W. M. Davis*) . 72
- Flood plains of meandering streams (*Sir Charles Lyell, Mark Twain*) 78
- The Red River rafts 90
- Floods (*J. W. Powell*) 92
- The floods of San Juan River (*Hugh D. Miser*) . 95
- The Nita Crevasse (*Lawrence C. Johnson*) . . 96
- The flood problem (*The New Republic, John R. Freeman*) 98
- Erosion and soil wastage (*Hugh H. Bennett*) . 106

IV. GLACIERS AND GLACIATION 118
- Development of the glacier hypothesis . . . 118
- Mountaineering in the Alps (*A. E. H. Tutton*) . 120
- Alpine glaciers (*Sir Charles Lyell*) 122
  - Glacial lakes (*A. E. H. Tutton*) 124
  - Early studies of glacier motion, I (*Sir Charles Lyell*) 126
  - Early studies of glacier motion, II (*John Tyndall*) 131
  - The Grimsel and the Eggishorn (*John Tyndall*) 134
- Glaciers as agents of erosion (*W. M. Davis*) . 137
- The origin of cirques (*Willard D. Johnson*) . . 147

V. GROUND WATER 151
- Lower limit of ground water 153
- Artesian wells (*T. C. Chamberlin*) 153
- The Jumbo disaster (*W. H. Norton*) 158
- Quality of ground water (*H. E. Gregory*) . . 160
- Limestone caverns 163
  - The size of caverns (*H. C. Hovey*) 163
  - Caverns as ancient dwelling places (*H. C. Hovey*) 165
  - Description of cavernous regions (*H. C. Hovey*) . 169
  - Effects of caverns on topography and drainage . 171
  - Caverns in Illyria (*D. A. Wray*) 173
  - The caverns and people of northern Yucatan (*Leon J. Cole*) 175
  - The region of the Causses (*S. Baring-Gould*) . 177
  - The desolateness of the Causses (Onésime Reclus quoted by *S. Baring-Gould*) 179
- Mechanical work of ground water 180
  - The Gros Ventre slide (*Eliot Blackwelder*) . . 180

CHAPTER PAGE
A violent landslide (*R. G. McConnell and R. W. Brock*) 184
Water witching (*O. E. Meinzer*) 186
VI. LAKES AND SWAMPS 189
Lake Bonneville (*G. K. Gilbert*) 189
Colorado River and the Salton Basin (*John C. Van Dyke*) 193
The Gros Ventre landslide lake (*William C. Alden*) 198
Preservation of organic matter in swamps (*Robert Bakewell*) 203
The formation of coal (*Thomas Huxley*) . . 204
Swamps in military operations (*H. E. Gregory*) . 209

VII. SHORELINES 211
Destruction of British coasts (*Sir Charles Lyell*) . 212
Changes along the New Jersey coast (*Lewis M. Haupt*) 220
Records at life-saving stations (*Lewis M. Haupt*) 221
The legal aspect of the problem (*Lewis M. Haupt*) 222
Changing of inlets (*Lewis M. Haupt*) 223
Changes of level 226
Human aspects of fiords (*J. W. Gregory*) . . 227
Nature of coastal problems (*Douglas W. Johnson*) 229
The Goose Creek oil field (*Wallace E. Pratt and Douglas W. Johnson*) 231

VIII. SEDIMENTS AND SEDIMENTARY ROCKS 237
Delta of the Po (*Sir Charles Lyell*) 237
Filling of the Adriatic Sea (*Sir Charles Lyell*) . 238
Sediment of the Rhone (*Sir Charles Lyell*) . . 240
True interpretation of sedimentary strata (*Sir Charles Lyell*) 245
Triassic sediments of Connecticut (*W. M. Davis*) 246
On a piece of chalk (*Thomas H. Huxley*) . . 252
Mining débris and San Francisco Bay (*W. M. Davis*) 262
Principles of sedimentation (*John Playfair*) . . 264

IX. VOLCANOES AND VOLCANISM 268
Eruption of Etna, 1928 (*Arnaldo Cortesi*) . . 269
Lava flows in snow, Etna (*Sir Charles Lyell*) . 274
History of Vesuvius and vicinity (*Sir Charles Lyell*) 277
Pompeii and Herculaneum (*Sir Charles Lyell*) . 287
General view of Mauna Loa (*J. D. Dana,* from Gilman) 293

CHAPTER PAGE
Great eruption of Skaptar Jokul (*Sir Charles Lyell*) 294
Volcanic melting of glaciers in Iceland (*Thomas A. Jaggar*) 297
The eruption of La Soufrière, May 7, 1902 (*T. Anderson and J. S. Flett*) 299
Premonitory symptoms 299
Preliminary stages of the eruption, Tuesday, May 6th 300
The climax of the eruption, the descent of the great black cloud 302
The avalanche of dust, sand, and stones . . 306
The hot blast 307
The epochal eruption of Pelée (*T. Anderson and J. S. Flett*) 310
Knowledge gained from Antillean eruptions (*T. Anderson and J. S. Flett*) 314
Additional light on La Soufrière and Pelée (*E. O. Hovey*) 316
Eruption of Pelée 322
Eruption of Katmai (*Press despatches*) . . . 330
Volcanology 333
Relation of Mauna Loa and Kilauea (*Thomas A. Jaggar*) 334
Explosive eruption of Kilauea, 1924 (*Thomas A. Jaggar* and *R. H. Finch*) 335
Future of Kilauea (*R. M. Wilson*) 338

X. MOVEMENTS OF THE EARTH'S CRUST 340
EARTHQUAKES 340
Eye-witness account of the Charleston earthquake (*Clarence E. Dutton*) 340
Surface waves at Charleston (*Clarence E. Dutton*) 349
Effects near the earthquake center (*Clarence E. Dutton*) 354
Experiences in other states (*Clarence E. Dutton*) 356
The New Madrid earthquake (*Myron L. Fuller*) . 360
Additional facts about New Madrid (*N. H. Heck*) 361
Cause of the New Madrid shock (*Myron L. Fuller*) 364
Yakutat Bay earthquake, Alaska (*R. S. Tarr and L. Martin*) 366
Chilean earthquake of 1822 (*Sir Charles Lyell*) . 370
Earthquake of Cutch, India (*Sir Charles Lyell*) . 373
Ancient views of earthquakes (*Aristotle,* by Webster) 374
Slow rising and sinking of land areas . . . 378
The temple of Jupiter Serapis (*Sir Charles Lyell*) 378

CHAPTER PAGE
Rise of the Scandinavian peninsula (*Sir Charles Lyell*) 385
Mountains 391
The Sierra Nevada (*Andrew C. Lawson*) . . 392

XI. METAMORPHISM 396
The old classification of rocks (*Sir Charles Lyell*) 398
Hutton's views (*Sir Archibald Geikie*) 401
The age of metamorphic rocks (*Sir Charles Lyell*) 402
The modern view 404

XII. LAND FORMS 406
Early perceptions of the sculpturing processes (*Georgius Agricola*) 406
Illustrations of the cycle of erosion (*W. M. Davis*) 407
The Appalachian landscape (*Bailey Willis*) . . 413
The first expedition down the Colorado (*J. W. Powell*) 416
The classification of valleys (*J. W. Powell*) . . 424
The record of the strata exposed in the Grand Cañon (*J. W. Powell*) 427
The desert 429
The desert east of the Sierra Nevada (*Eliot Lord*) 429
The deserts of the southern Great Basin (*John C. Van Dyke*) 430
An account of a sheetflood (J. S. Douglas, *quoted by Eliot Blackwelder*) 433
The Great Basin in '49 (*W. L. Manly*) 436
The influence of terrain on warfare 440
The rivers of the clay plain (*D. W. Johnson*) . 441
Battle of the Yser (*D. W. Johnson*) 444
The battlefield of the Trentino (*D. W. Johnson*). 445
The military campaigns against Germany's African colonies (*G. M. Wrigley*) 448

XIII. GEOLOGY IN MODERN LIFE 452
Geology and mining 453
Mining law 453
Development of a "Common Law" of mining in California (*C. H. Shamel*) 454
Placer claims 456
Horizontal veins (*C. H. Shamel*) 456
The Comstock Lode (*Eliot Lord*) 458
Property in meteorites (*C. H. Shamel*) 470
The investigation of a claim (*D. W. Johnson*) . 472
Reservoir sites (*Kirk Bryan*) 476
Tunneling operations (*J. F. Kemp*) 477

CHAPTER PAGE
The geological detective (*C. P. Berkey*) . . 478
A practical use of paleontology 479
Physiography and the law (*D. W. Johnson*) . . 480
Property boundaries (*D. W. Johnson*) . . . 485
The Red River boundary suit (*Sellards, Tharp, and Hill*) 491
Contentions of the United States and Oklahoma . 493
Contentions of the state of Texas 495
The decision of the Supreme Court . . . 496
Other boundary cases (*D. W. Johnson*) . . 497
Geology in the World War (*A. H. Brooks*) . . 498
Mining (*A. H. Brooks*) 500
Relation of geological structure to trench and dugout locations (*D. W. Johnson*) 501

XIV. THE SCOPE AND METHOD OF GEOLOGY 505
Universality of the geologic processes (*John Woodward*) 505
The doctrine of uniformitarianism (*James Hutton, Sir Charles Lyell*) 506
Prejudices which have retarded the progress of geology (*Sir Charles Lyell*) 513

ILLUSTRATIONS

Plates

Diamond Falls and Mount Jackson, Glacier National Park . . . . *Frontispiece*

PLATE		FACING PAGE
I.	Grand Canyon of the Yellowstone	74
II.	Zion Canyon, Utah	75
III.	Snake River Canyon, Idaho	90
IVA.	Rise of the Salton Sea, California	91
IVB.	Ancient waterline around the Salton Basin .	91
VA.	A "sand-boil" on the lower Mississippi . .	106
VB.	The Mississippi in flood	106
VIA.	Land rendered valueless by careless plowing .	107
VIB.	A recent gully in Mississippi	107
VIIA.	Glaciated trough in the Sierra Nevada . .	122
VIIB.	Terminal moraine of a valley glacier . . .	122
VIIIA.	Mount Cook and Hooker Glacier, New Zealand	123
VIIIB.	Glaciated valleys in New Zealand	123
IX.	Valley glaciers on volcanic cones in Oregon .	140
X.	Mount Hood, Oregon	141
XIA.	Entrance to a cavern, West Virginia . . .	152
XIB.	Exit of an underground river	152
XIIA.	Erosion of limestone in the Dinaric Karst . .	153
XIIB.	Results of solution of limestone, Dinaric Karst .	153
XIII.	Entrance to Carlsbad Cavern, New Mexico .	186
XIV.	Room in Carlsbad Cavern, New Mexico . .	187
XV.	Crater Lake, Oregon	202
XVI.	Terraces of ancient Lake Bonneville, Utah .	203
XVII.	Relief model of the ocean floor bordering eastern North America	212
XVIIIA.	Rocky coast of Skomer Island, Pembroke, Wales	218
XVIIIB.	Waves attacking old marine deposits . . .	218
XIXA.	Arch eroded by the sea, Cornwall	219
XIXB.	Beach and sand hills in Cornwall	219
XXA.	The Rock of Gibraltar	234
XXB.	Lake Tarawera, New Zealand	234
XXI.	Marine terrace at Santa Monica, California .	235
XXII.	Horizontal sedimentary rocks, Pine Canyon, New Mexico	250
XXIIIA.	Conglomerate being attacked by the waves . .	251
XXIIIB.	Marine rocks exposed in a desert	251

PLATE FACING PAGE
XXIV. Piedmont slope of detritus, Medicine Bow Range, Wyoming . . . 266
XXVA. Crescentic sand dune in a Nevada desert . . 267
XXVB. Canyon del Muerto, New Mexico 267
XXVIA. Lava flow from Mauna Loa, Hawaii . . . 282
XXVIB. Lava flow entering the sea, Hawaii . . . 282
XXVIIA. Volcanic boulder thrown from Kilauea, Hawaii . 283
XXVIIB. Solidified lava cascade, Hawaii 283
XXVIIIA. Advancing lava flow from Mauna Loa . . 298
XXVIIIB. Footprints in hardened volcanic ash, Hawaii . 298
XXIXA. A lava pool at night, Kilauea, Hawaii . . . 299
XXIXB. Keanakakoi Crater, Hawaii 299
XXXA. Lava tree, Hawaii 330
XXXB. Eruption of Kilauea, 1924 330
XXXIA. Wairakei Geyser, New Zealand 331
XXXIB. Waimangu Geyser, New Zealand 331
XXXIIA. Arch at Stanford University after the earthquake 346
XXXIIB. Statue affected by the earthquake of 1906 . . 346
XXXIIIA. Walls shaken down by the earthquake of 1906 . 347
XXXIIIB. Front of Steens Mountain, Oregon, made by faulting 347
XXXIV. Eroded fault scarp, San Bernardino Mountains, California 362
XXXV. A new fault scarp, San Bernardino Mountains, California 363
XXXVI. Top of the Sierra Nevada 378
XXXVII. Mountains made by faulting and erosion . . 379
XXXVIII. Dunes in the Colorado Desert, California . . 410
XXXIXA. Mudflow in the desert, Nevada 411
XXXIXB. Desert basin in Nevada 411
XL. Buttes seen from the air 426
XLI. Canyon de Chelly, Arizona 427
XLII. Grand Canyon of the Colorado 442
XLIII. Taiialone Mesa, New Mexico 443
XLIVA. Gold dredge in the Sacramento Valley, California 458
XLIVB. Results of gold dredging 458
XLVA. Oil field near Hollywood, California . . . 459
XLVB. Oil gusher and reservoir, Lakeview, California . 459
XLVI. Copper mine at Bingham, Utah 466
XLVII. Vermont marble quarry 467

ILLUSTRATIONS

Text Figures

FIGURE PAGE

1. A normally eroded mountain mass 141
2. The same mountain mass strongly affected by glaciers which still occupy its valleys 144
3. The same mountain mass shortly after the glaciers have melted 145
4. Goose Creek region before subsidence 232
5. Goose Creek region after subsidence 233
6. Truncated appearance of the summit of Mt. Etna . . 274
7. View from the summit of Mt. Etna into the Val del Bove 275
8. Map showing Vesuvius, the Phlegræan Fields, and surroundings 280
9. The Phlegræan Fields 281
10. The Temple of Jupiter Serapis 381
11. The first illustration of an antecedent valley . . . 425
12. Supposed relations below ground in the magnetite investigation 474
13. The relation of the drill cores to the foliation of the rock 475
14. Tunnel traversing anticlinal arch of hard sandstone covered by shales 478
15. Features involved in the New York high-water line controversy 482
16. Cross-section of a typical hill in the Somme battlefield, showing trench locations 502

GEOLOGY FROM ORIGINAL SOURCES

CHAPTER I

MINERALS AND ROCKS

Minerals

Man and Minerals. From the earliest times down to the present minerals have played an exceedingly important part in the development and progress of the human race. Primitive man made his first rude weapons and utensils from stone, such as flint and other compact varieties of quartz which were easily chipped into rough shape. These artifacts are largely the material upon which the archæologist builds his concept of the human kind in the early paleolithic age, called the old or rough-stone age. As man became more adept in the art of working stones into a required shape, he was able to smooth them, and sometimes to give them a crude polish. With this knowledge he emerged into the neolithic age, that is, the new or smooth-stone age.

With the development of the art of recovering metals from their ores, man passed successively through the copper, bronze, and iron ages, in which minerals were even more important than in the stone age. Then came the discovery of the fact that coal would burn, and the coal age was inaugurated. The present time is often called the motor age. The motor is an assemblage of metals, and, accordingly, man's dependency upon minerals is to-day greater than ever before.

When the study of the substances upon the earth was first begun, they were divided into three kingdoms: the animal, the vegetable, and the mineral kingdoms. All animal life of the land, sea, and air was referred to the first kingdom. With a more intensive study of that group of organisms, zoölogy was developed, and with it such allied sciences as anatomy, physiology, animal breeding, and paleozoölogy. The vegetable kingdom included all the plants, from fungi and lichens to trees and flowers. Botany, and such related sciences as agriculture, forestry, and paleobotany, are the outgrowth of study of the vegetable kingdom. The early naturalists assigned to the mineral kingdom the entire residue of naturally occurring substances: minerals, the rocks, the soils, the air, the seas, lakes, and rivers. From the investigation of this kingdom a large number of modern sciences have developed, including mineralogy, geology, chemistry, physics, meteorology, and oceanography.

The preceding paragraphs from Kraus and Holden's *Gems and Gem Materials* (1925, pp. 1-2) attest the value of minerals to man. Some of these have interested him since his earliest days because of their abundance and the useful purposes to which they could be applied, others because of their rarity and beauty; but he has not been content merely to use them. The questions "what is a mineral?" and "how does a mineral assume its particular form?" puzzled him from the start and in the attempt to answer them, with their practical as well as abstract value, the science of mineralogy developed. It is a difficult and technical subject if all of its details are considered, but its more general aspects are fascinating to the most casual student of Nature. The following discussion (Whitlock, 1925, pp. 10-11) emphasizes the importance of the minerals and their place in nature:

The Substance of the Earth

When we consider the various kinds of material that make up the world about us, we usually find that the familiar things, —those that we know most about—are the animals and the plants. Yet because these *organic* things, which we call organisms, and of which we ourselves are a part, only exist on the surface of the earth, and in the water which covers part of this surface, they really form comparatively little of the mass of the earth on which we live. Underneath the grass roots begins the silent, immobile kingdom of the minerals. Extending to an unknown depth below us are miles upon miles of rocks all composed of minerals. Our knowledge of these substances which form the huge mass of the earth is limited to those of them which are to be found within a comparatively thin shell, ten miles in thickness and encircling the earth, which represents all we are able to see and study of the solid interior.

We have access to this part of the crust of the earth because the rocks have in many places been folded, then worn away until their edges are exposed, thus letting us who live on the exposed edges examine them to about the depth mentioned (ten miles). Of what, then, is this "sample" of our planet made? And how can we learn the story of this silent realm of nature beneath our feet?

The researches of chemists tell us that everything to be found in the world is made up of combinations of less than a hundred different substances which are called elements, because, up to the present time, no one has been able to prove that they are themselves made up of simpler substances. These elements or ultimate substances, then, are the materials or "earth stuff" which nature has used to build up the vast structure of the world. They were probably all present in the mass of matter from which the planet was born, and they have combined and recombined to form natural compounds throughout the periods of its life. We know this because we have found many instances where a natural substance has been altered into quite a different substance through the action of natural forces. We have ample evidence that these natural combinations of world materials, to which we give the name of minerals, have been fused together as if in a melting pot and have emerged from the cooled solid mass as different combinations.

Crystals

The man who sees for the first time the smooth, shiny faces of a natural crystal and the geometrical pattern in which they are arranged is often loath to believe that the object before him has not been fashioned by man. It was a common practice in ancient and medieval times to use the more beautiful and durable minerals for decoration exactly as Nature had fashioned them and, though this practice is rare to-day, these crystals are on exhibition in all mineral collections. The extraordinary variety of forms exhibited, some simple and some amazingly complex, led men to investigate the answer to the second question—"How does a mineral assume its particular form?" An answer to this is contained in the following quotation (Whitlock, 1925, pp. 17-20):

> If we were to observe a number of examples of minerals of different kinds which have been gathered together, that is to say if we were to inspect a Collection of Minerals, we would be impressed not so much by the beautiful colors which some of them display, as by the remarkably even and regular shapes which they have assumed. It would seem as though nature had molded them into geometrical shapes and then polished the sides so that they glitter like a gem in a jeweler's show case.
>
> Looking a little more closely at this singular tendency of minerals to assume regular shapes we will come upon a still more remarkable fact. We will notice that in the case of some one kind of a mineral (like the fluoride of calcium which is called *fluorite*) a particular shape (such as a cube) is characteristic of the mineral. And this discovery that fluoride of calcium almost always occurs in the form of cubes opens the way to two very significant questions:
>
> 1.—Does each kind of mineral have a characteristic shape, just as every animal or plant?
>
> 2.—If so, is this shape given to it by the chemical elements which compose it?
>
> It took scientific men a long time in the early days of the development of mineralogy to find the answer to the first question, and it is only within very recent years that the second one has been really answered.
>
> In the first place, it would seem that in most cases a mineral such as carbonate of calcium (calcite), did *not* have one

particular shape which it always assumed. In point of fact this particular mineral has hundreds of shapes. But, and this is the essential fact, *all of these hundreds of shapes are related by certain very definite mathematical laws and conform to certain requirements of symmetry which may be recognized almost as easily as the symmetry of the three-leaved clover.* In other words calcite crystals always form in a systematic group of shapes.

We can, then, answer the first question in this way:—Almost every mineral, together with most of the other chemical compounds, when allowed to solidify without interference from the outside, will produce a solid bounded by smooth, bright faces forming sharp well-defined angles. This is due to an orderly cohesive attraction between particles of its matter and is known as crystallization. Crystallization is, in fact, the organizing or structure making principal of inorganic nature, producing definite forms for each species of inorganic matter as life does for each living species.

How Crystals Are Formed.—Let us then devote a little time to the consideration of this phenomenon of cohesion between particles of matter which we call crystallization. In the first place we should get a very definite idea of what is meant by "particles of matter." The phenomenon of crystallization is what we have learned to call a *physical* manifestation, and the force of cohesion between the particles of matter, into which we are going to examine, is a *physical* force. Very early in the development of the science of physics men learned to speak of the units acted upon by a physical force as molecules. A rain drop falling through the air is made up of molecules of water loosely held together by the force of cohesion. We know nothing whatever about the shape of these molecules and not very much about their size, but on the latter point we are beginning to get a little more light. Lord Kelvin has stated that if we were to magnify the raindrop about which we have just been speaking, to the size of the earth, its molecules would have a size somewhat between that of an orange and a marble. So we are, at the very start, confronted with the idea that in picturing to ourselves these particles of matter, we must imagine them as almost infinitely small, so small in fact that they are far beyond the range of vision of even the most powerful microscope.

Another fact about the molecules that compose all kinds of matter is that they are never quite in contact with one another. This is apparent when we think of the mercury in the bulb of a thermometer. When the air is warm the space between its molecules is greater and the column of mercury rises. On the other hand when the weather gets cold the space between the molecules becomes smaller and the thermometer registers lower.

In every gas such as water vapor the space between the molecules is so large that its particles of matter have no cohesion, and in every liquid the corresponding space is reduced to a point where the molecules are held loosely together by cohesion so that they move freely and are not definitely linked one with another. But as soon as the space between the molecules is reduced to a certain point, a set of forces comes into play between them which *link them together,* and which link them together *along certain definite lines of direction.* It is as though the forces of cohesion which loosely bound together the molecules of a liquid, had, when that liquid became a solid, been oriented along definite lines of attraction.

The molecules of every mineral, with a few rare exceptions,[1] possess this power of attracting to themselves other molecules of the same kind along definite directions of crystallizing force, which directions, as well as the relative intensities of the forces, are distinctive for the molecules of different kinds of substances. And they are capable under favorable conditions of building up orderly structures of these molecules, in much the same way that a brick layer builds bricks into a wall.

---

[1] It is possible that these exceptions to the almost universal rule of crystallization in minerals are in reality not exceptions at all. The mineral turquoise was for a long time assumed to be without crystallization, that is, *amorphous,* and it was only in 1911 that crystals of it were found and identified.

Crystalline Structure

Not all crystallized substances exhibit the outward symmetry described above. The minerals that grow together to form a rock interfere with one another and so cannot develop their characteristic form. The last ones to form, in particular, have to fill the space that is left. The crystalline structure is present in each mineral grain, but its outward expression is prevented. This subject is discussed in the following quotation (Whitlock, 1925, pp. 37-41):

> A factor that plays a very important part in the development of crystals is the relative length of time consumed in their formation. Crystals formed by a slow process of building up of their molecules tend to become large and well developed, while on the other hand rapid action of the crystal forming forces produce small and ill developed crystal individuals. It is as though these forces require for their perfect operation a certain *deliberation,* and just as a regiment of soldiers scattered promiscuously over a field need an appreciable time to come into formation, so the particles of matter that come together to form a crystal require time to effect the orderly arrangement which we find in highest perfection in large and well formed individuals. To such an extent is this so that we find, in the case of minerals that have formed very rapidly, no individual crystals at all, only a mass of mineral matter whose sole evidence of crystallization is revealed by its optical properties.
>
> *Crystalline Aggregates.*—Between the perfectly formed crystal developed to ideal proportions and free from distortion, and such massive bodies which do not possess any outward token of crystallization, we find among minerals a wide range of examples of molecular architecture which are known as crystalline aggregates. Many of these mimic the forms of animate nature, producing fanciful shapes of great diversity and

beauty. Water, which is so common a substance that few of us realize that it is really a mineral, furnishes us with an admirable instance of the wealth of exquisite patterns produced by crystallization. Where water vapor is cooled slowly to just the point of freezing its molecules are drawn together to form little flat six-sided crystals familiar to any one who has looked closely at snowflakes. With somewhat more rapid cooling of the air the minute nucleus of the snow crystal becomes the center of intricate branching and starlike forms of wonderful symmetry. . . . Where water vapor consolidates on a cold sheet of glass, as a window pane, the water crystals grow much more rapidly and interlacing patterns of rods, produced by one tiny crystal forming against another, or branching, fernlike forms result. Lastly, where the dripping water is consolidated by the cold, the rounded shapes of icicles, resulting from the quick solidification of a liquid, give no outward evidence of the inward ordering of their molecules, although this arrangement is the same that has produced the snow crystal and the window frost. The knowledge of how window frost is produced enables us to understand the meaning of the so called *dendritic* structure, assumed by a number of minerals. Such minute and intimate crystal groupings as are to be seen in moss agate bear a very close resemblance to the delicate tracery of the vegetable world, and at first glance we are almost forced to the belief that they are in reality fossil plants. However, we have but to compare them with the designs that the touch of winter paints upon our window pane to realize their true nature.

Gems

A certain number of minerals are particularly attractive because of their color or because of their lustre and their ability to divide the white light that falls upon them into its component parts and return it as a flash of varying colors. Not all the beautifully colored minerals can be used for decoration, for many of the finest hues in Nature belong to minerals too soft to be durable, or to those that alter readily upon exposure to the atmosphere and lose their beauty. Those that are hard, that retain their splendor, and that are rare enough so that not every one can own them, attain a certain value and are classed as the precious stones and gems. The qualifications of such minerals are outlined below (Kraus and Holden, 1925, pp. 3-4):

> Minerals, in order to be suitable for use as gems, must possess as many as possible of the following qualifications: (1) *splendor* or *beauty;* (2) *durability;* (3) *rarity;* and (4) *fashion.* Rarely are all of these qualifications possessed by a single gem. The diamond, however, has each of these properties to a marked degree, and, accordingly, is the most generally esteemed gem.
>
> Splendor or beauty in a gem depends upon its transparency, brilliancy, luster, fire, and color. . . . A colored diamond is almost alone among gems in having all of these desirable qualities. Even white diamonds fall short because of lack of color. Rubies and emeralds have very desirable colors, but their brilliancy and fire are not exceptional. The opal is attractive mainly because of its play of colors. Turquoise makes its appeal by color alone, for it is dull and opaque. Many other illustrations might be given.
>
> It often happens that beautiful minerals are too soft to wear well, except in brooches or pins, where they are not so much exposed to abrasion as are gems mounted in rings. Such minerals lack durability and are very easily scratched. The satin spar variety of gypsum, with its attractive sheen and silky luster, is much too soft to be of value as a gem. A precious stone should be harder than the dust particles in the air, which are largely composed of a rather hard mineral, quartz. For this reason the most valuable stones are those which are decidedly harder than quartz: diamond, ruby, sapphire, and emerald. . . .
>
> Rarity is a valued attribute in gems. It is natural to esteem most highly things which are scarce, even though they may not be superior in their intrinsic qualities to many commoner sub-

stances. On this account some gems which are beautiful and durable but not rare make little appeal. Garnets are an illustration. Though often very attractive, they are generally worth little more than the cost of the cutting. The common mineral beryl occurs in many colors, blue-green, golden-yellow, pink, and emerald-green. The green variety known as emerald is the rarest and most valuable, even though it is scarcely more beautiful than some of the others.

The last factor in determining the suitability of a mineral for gem purposes is fashion or vogue. The effect of fashion upon the value of gems is enormous. A gem may be very popular at some period—perhaps it has been worn by royalty or leaders of fashion—only to fall back into its former unimportance at a later date. For instance, a short time ago news items stated that emeralds were greatly in vogue in England because Princess Mary chose that gem for her engagement ring. Some colors are always popular, such as reds, blues, and greens, while yellow is not commonly in demand. Certain gems are invariably fashionable, especially the diamond, ruby, sapphire, and emerald.

A number of gems are locally popular in the district in which they occur. This constitutes another phase of the influence of fashion on the wearing of gems. Examples of these locally used gems are: californite, a variety of vesuvianite, in California; chlorastrolite, thomsonite, and datolite in northern Michigan; tourmaline in Maine; malachite in Russia.

The Naming of Gems

The popular names of gems are often different from those in use by the mineralogist. This leads to ambiguity, much of which is unavoidable, since the names were given in a period long antedating the modern scientific nomenclature. A part of the ambiguity, on the other hand, results from the fact that names are given to ordinarily low-priced gems that simulate the name of an expensive precious stone, and it is well for the prospective purchaser to know what some of these names really mean. The following quotation (Kraus and Holden, 1925, pp. 87-88) gives the commoner of these names:

> Many of the popular names of gems are a heritage, having been in use long before mineralogy was developed as a science. They do not conform to the modern technical usage. But they are firmly established and it would be quite impossible to replace them in a short time with the more accurate scientific names. Among these older names may be cited for illustration: agate, from the Greek; amber, Arabic; amethyst, Greek, the name meaning "without drunkenness," since the stone was regarded as a remedy for intoxication; beryl, Greek, probably from the Sanskrit originally; diamond and emerald, Greek; garnet, Latin; jade, Spanish; opal, Sanskrit; quartz, German; ruby, Latin; sapphire, Oriental; and turquoise, French.
>
> The names now given to minerals end in *-ite*. Among these names are azurite, chrysolite, fluorite, malachite, smithsonite, and vesuvianite. It is interesting to note that the names of the majority of gem minerals are of the old form, especially those which are the most precious. This indicates that they were known at an early date. On the other hand, minerals not especially valuable as gems usually have the ending *-ite,* significant of their relatively recent recognition.
>
> Considerable ambiguity has been occasioned by the use of the popular gem names by jewelers, simultaneously with the employment of the scientific nomenclature by the mineralogist. While the popular names are in some respects desirable and ought to be retained, and indeed for some minerals there are no other names, they lack the precision and accuracy of those assigned by scientists. The popular names lend themselves more readily to unscrupulous practices in the selling of gems. In order to increase its sale value a cheap stone is often sold under a name closely resembling that of a valuable gem. For instance, when some red stones are sold they are not infrequently given names which suggest to the uninformed purchaser that they are a variety of ruby. Thus red pyrope

garnets are sold under such trade names as American ruby, Arizona ruby, California ruby, Cape ruby, Colorado ruby, Montana ruby, and Rocky Mountain ruby. Likewise red and orange spinels are called Balas ruby or rubicelle. A mineral so different from the true ruby as rose quartz is frequently offered under the name Bohemian ruby. Rose and pink topaz may be sold as Brazilian ruby, and red or pink tourmaline is called rubellite or Siberian ruby. While these stones are perfectly good in their own right and are very attractive as gems, the purchaser should know just exactly what he is buying. That knowledge is hardly likely to be his when such deceiving names are used.

Another example of this practice is the assigning to gems names of stones which are frequently better known or more valuable than the one being sold, preceded by the word "Oriental." In this way the sale value is greatly increased. For example, light green corundum is often called Oriental aquamarine. It is obvious that this ambiguity could be avoided by the use of the scientific names as accepted by the mineralogist.

Artificial and Imitation Gems

It is natural that man should try to reproduce in the laboratory those products of Nature's synthesis that he prizes most highly. Some of these "reproductions" are valueless. They are more or less clever imitations constructed to fool the unwary. Others are stones, similar in most of their properties to the natural stones, that differ only by being constructed in the laboratory.

Some gems such as the emerald defy reproduction; others, the diamond, for instance, can be reproduced only in minute fragments; the ruby and the sapphire on the other hand can be manufactured by man so as to have all the physical properties that make the natural stones valuable. The following extracts (Kraus and Holden, 1925, pp. 89-90, 91-93, 95-97, 103-104) consider these various reproductions and explain how the expert can distinguish the natural from the synthetic stones even when they are alike in their ordinary properties:

. . . Gems have been used from earliest antiquity for personal adornment and ornamentation. Because many of the more precious gems are very expensive their use has obviously been limited to those able to purchase them. Hence, to satisfy the equally strong desire on the part of those financially less fortunate, various types of rather inexpensive manufactured stones are annually placed upon the market in comparatively large quantities. In this chapter some of the more important kinds of material used in this way will be described.

Manufactured stones may be classified as follows:

1. Doublets and triplets.
2. Imitation stones.
3. Treated stones.
4. Artificial or synthetic stones.

Accordingly, the term "manufactured stones" includes gem material which has been made entirely in the laboratory, as well as some natural stones which have been treated, manipulated, or "doctored" in such a way as to increase their sale value.

. . . There are two types of doublets, *true doublets* and *false doublets*. The *true doublet* consists of two sections, each of genuine material, joined with an invisible cement to produce a larger stone, the value of which would naturally be greater than the sum of the values of the two smaller pieces. The layer of cement in these doublets may be detected by immersing the stone in a liquid with an index of refraction approximately equal to that of the gem fragments. The cement is frequently soluble in alcohol or chloroform, so that when a doublet is soaked in one of these liquids the two portions may fall apart. Diamond fragments are sometimes used in making true doublets, the crown being one piece, the pavilion another. The two sections are so cut that they are cemented together at the girdle, which obviously makes it more difficult to recognize the true character of the stone.

The *false doublet* has a genuine crown, while the pavilion ordinarily consists of glass or of an inferior stone. For instance, a thin slice of ruby might be backed with red glass, garnet, or some other inexpensive red stone. The exposed portion, being genuine, would stand successfully the usual tests that might be made upon it. Further, a thin slice of a comparatively hard stone, such as garnet, may be used for the upper portion of the doublet, to withstand abrasion, while the lower portion may be of glass of any desired color. Many gems are imitated in this way.

. . . Imitation gems are even more valueless than doublets or triplets, for they contain no genuine material whatsoever. They are manufactured from special types of glass known as *paste* or *strass*. Paste is a dense, very transparent, and highly refractive flint glass containing a large proportion of lead, which gives it the density and refractivity. The following is an example of one of the mixtures used in making paste: 300 parts of quartz, 470 of red lead, 163 of pure potash, 22 of borax, and 1 of white arsenic. This glass may be used to imitate the diamond. If a colored stone is to be simulated, pigments must be added to the mixture. These pigments used are compounds of certain metals. Examples are the compounds of manganese, which give a purple color; of cobalt, blue; of copper, red; of iron, yellow to green; and of chromium, green and red.

In some cases these stones are very carefully cut, but often the molten glass is simply poured into properly shaped molds, and allowed to become solid. The edges of such molded stones are rounded and dull, unless the stones are subsequently ground and polished to enhance their sale value.

Paste may be identified by the following characteristics: (1) It is *softer* than the gems for which it is substituted, being easily scratched by a file. . . . (3) It has a good *conchoidal fracture,* which may usually be observed near the prongs used in mounting the stone. (4) Although great care is taken in melting the glass, *air bubbles* are usually present, which are sometimes so prominent as to be readily seen without immersing the stone in a liquid. Air bubbles are not found in natural stones. . . .

In distinguishing colorless paste from the diamond, it is to be noted that the paste imitation feels warm to the touch, while the diamond, being a much better conductor of heat, has a cold feel. Because of the surface tension relationships a drop of water spreads out upon glass, but assumes a spherical shape on the diamond. This test may be applied by dipping a match stick or toothpick into water and gently touching the surface of the stone with the drop which is taken up by the stick. Because of their lower refractivity paste stones have not the brilliancy of the diamond, since light passes through the lower facets without experiencing total reflection. To increase the brilliancy the pavilion and culet of paste stones may be coated with mercury or tin-foil, which reflect the light impinging upon these facets.

"Goldstone" is a very common imitation of yellow or red aventurine quartz. In making this imitation copper filings are stirred into molten glass. During this process, air is entrapped, causing the formation of air bubbles, which help to reveal the true character of the goldstone. Frequently the polished surface is pitted where it has been cut through such air bubbles.

. . . Aside from the fact that artificial or synthetic stones are made in the laboratory, they are in other respects essentially the same as the natural stones. The elements composing these artificial stones are combined by chemical processes. A synthetic ruby, for example, consists of Al_2O_3 just as does the natural ruby. Besides having the same chemical composition, synthetics have the same physical properties as natural stones. . . . But the process by which they are made usually causes the development within the stones of certain incidental and characterizing features which may be used for purposes of identification.

In the development of the manufacture of artificial gems, one of the earliest attempts consisted of fusing together fragments of the natural material. The larger stones, produced in this way, were called *reconstructed gems*. This process was applied to the ruby, especially. The stones made in this way were not clear, and were poor in color and often brittle. Later, in 1895, Michaud succeeded better, and his reconstructed rubies found a market in France, Germany, America, and India. It is suspected that in India some of the reconstructed rubies were mixed with natural gems and sold as such. In Michaud's process a fairly large fragment of natural ruby was placed in a revolving platinum crucible and heated to about 1800° C. Smaller chips were added from time to time, and were fused to the original fragment. In this way stones of fairly large sizes were obtained, even though the product would sometimes burst asunder. Reconstructed rubies are no longer manufactured, but have been displaced by the more successful artificial stones. . . .

Artificial Diamonds.—Because of its great value, many attempts have been made to produce the diamond in the laboratory. The process generally followed is to dissolve some form of carbon in a suitable solvent, and then to allow it to crystallize out. Of the many attempts, perhaps those of Moissan and of Noble and Crookes are most worthy of a brief description.

Moissan was able to produce artificial diamonds of microscopic size by dissolving carbon, prepared by the ignition of sugar, in molten iron, and suddenly cooling the mass. The iron was melted in an electric furnace by means of a current of 700 amperes and 40 volts. The temperature attained was about 4000° C. At this temperature the iron quickly melted and became saturated with carbon. The crucible was then suddenly cooled in a water bath. A rigid crust of iron was formed, while the interior of the mass remained molten. As a result of this condition within the mass an enormous pressure was developed. Part of the carbon crystallized out as the diamond, the rest as graphite. To separate the diamonds from the iron in which they were formed the ingot was dissolved by successive treatments with nitro-hydrochloric acid. The bulky residue consisted of graphite, flakes of black diamond, and a small quantity of transparent, colorless diamond. The graphite and other impurities were chemically removed, leaving behind the unattacked diamonds. The crystals formed in this way were rarely if ever whole, but appeared to be broken, as if liberation from the intense pressure prevailing when they were formed had allowed them to burst. In this connection it is interesting to note that natural crystals of the diamond from South Africa have also been known to burst asunder when removed from the peridotite or blue ground in which they were formed.

Sir William Crookes in 1906 reported another method for the production of the diamond artificially. Sir Andrew Noble had previously shown that when the powerful explosive cordite is exploded in a closed steel cylinder a pressure of 50 tons per square inch and a temperature of 5100° C. are momentarily attained. These conditions should be favorable for the liquefaction of carbon. It was thought that if the explosion were to extend over a sufficient period to permit the carbon to be liquefied, it might then solidify in the crystalline form of the diamond. In the experiment Noble used cordite containing a slight excess of carbon, and collected the residue after the explosion. This residue was examined by Crookes, who identified minute crystals of the diamond, the largest being only 0.5 millimeter in length. These had all the properties of the natural stones.

On various occasions the diamond has been reported as occurring in microscopic crystals in steels, especially in those which had been cooled under pressure. The hardness of certain steels may be due to the presence of this crystalline form of carbon. The Canyon Diablo iron meteorite, from Arizona, was found to contain minute diamonds. . . .

Therefore, all attempts to produce the diamond artificially have resulted in the formation of only small microscopic stones of no commercial value. . . .

. . . While . . . differences between natural and artificial rubies and sapphires are obviously not readily recognized by the untrained observer, the expert is in general able to pass judgment on the character of the material. In the case of rather small stones, however, which have been selected and fashioned with great care, the distinguishing criteria may be entirely absent. It is of interest to point out that the production of artificial rubies and sapphires on a commercial scale was not begun until the opening of the present century. Consequently, rubies and sapphires with a history considerably antedating the year 1900 are in all likelihood natural.

. . . Since natural and artificial rubies and sapphires are alike in all important essentials, naturally the artificial stones are in great demand. Furthermore, this popularity has been stimulated by the fact that cut artificial stones may be bought at various prices up to $10 per carat, depending upon the quality, while the price of natural stones is many times higher. The demand for natural stones has consequently fallen off greatly. It is also worthy of note that comparatively large quantities of cut, artificial rubies and sapphires are used as the jewels of watches, and in scientific apparatus where hard bearing surfaces are required.

The Uses of Minerals

The uses to which minerals may be put are varied. The gem stones may be used essentially as formed by Nature. They are merely cut and polished, the better to bring out their natural beauty. Hard minerals are extracted from the rocks that hold them and used as grinding substances. The fibres of asbestos are separated and woven or pressed for various uses. Rock salt needs merely to be purified. Calcite, when present in large quantities as in limestone, is burned for quicklime. Other minerals, notably those that contain valuable metallic elements, must undergo the more or less elaborate, large-scale chemical treatment known as smelting before they will yield the metal for which they were mined. The following extract treats briefly the many uses of minerals (Jones and Whittlesey, 1925, p. 267):

The mineral resources of the earth (aside from soil and water) differ enormously in value and utility, but they are similar in that their distribution bears little or no definable relationship to the other elements of the present-day natural environment (climate, land forms, water features, soil, plant life, and animals), and their formation is so slow that the supply, once exhausted, cannot be renewed in the lifetime of the human race. In these respects they differ from plants, to cite another of the earth's resources. Clearly, plant life is intimately related to climate, land forms, soil, waters, and in many cases to animal life. Clearly also, most plants grow in a span measurable in terms of a single human generation; indeed, most plants of economic value are annuals, and their continued production by man is, therefore, relatively simple.

The abundance and distribution of minerals profoundly affects their utility. Clay and sand are so widely and generously distributed that few places in the world lack either of them, and still fewer lack both. Hence brick, tile, and the baser constituents of mortar and concrete normally are produced in or very near the place where they are used. Other building materials are widely, although not universally, distributed. These include gravel, stone suitable for crushing or for blocks, limestone for mortar and cement, sand from which glass can be made, and clay of the special sort required for pottery. Some finer materials, such as marble, slate, and first-class building limestone or sandstone, outcrop only here and there, and hence may be transported in small quantities hundreds of miles to their destination. The mineral fuels (coal and petroleum), and ores from which the metals of industry are derived, are more narrowly restricted in distribution than are most of the building stones. Still rarer are the precious stones and metals, which occupy the end of the scale opposite to plebeian clay and sand.

Although quantity in existence is one of the factors in the value of mineral products, it is by no means the only one. Certain of the rarer jewels, such as diamonds, sapphires, and emeralds derive a fictitious added value from their very scarcity. Wherever gold or silver is used as a standard of coinage, its value is arbitrarily fixed, and probably heightened, as well. The value of the commoner minerals is modified by the existence or lack of substitutes. Thus in recent years aluminum kitchenware has all but driven tinware out of the market. The uses and substitutions for most minerals are continually fluctuating so widely as to render the market highly unstable.

Rocks

Those who wish to understand the history of the Earth must first learn the language in which it is recorded. The land forms that surround us, the fossils embedded in the rocks, and the very stones themselves will speak to him who knows their tongue and tell of happenings in ages long past.

The rocks we see are the outer framework of the Earth and every piece that can be examined tells its own part of the story of our planet. The igneous rocks tell of volcanoes, long dead, perhaps, and obliterated from the face of the globe; or of events that transpired deep within the crust of the Earth. The sedimentary rocks trace the history of the break-up and the transportation of fragments of older formations, their burial and hardening into stone with the remains of living creatures entombed within them. The metamorphic rocks, in their turn, tell the strange tale of transformations effected far down below the surface of the Earth.

Knowledge of how to decipher this story was not gained in a day. It was necessary to describe and to compare rocks from all quarters of the globe and then to classify them into logical groups before their individual tales could be woven into a connected history. This work will always be incomplete, for Nature does not fashion substances according to a plan easily grasped by man and his artificial groupings ever fall short of perfection. Nevertheless the light that it sheds illumines many of the recesses of the past.

The way in which the substance and character of a rock can be made to reveal its history is admirably recounted by Huxley in his essay "On a Piece of Chalk" which is quoted in Chapter VIII.

Intelligent use of experimental methods has added much to our comprehension of how rocks, especially igneous rocks, are formed.

Sir James Hall's Experiments

We are often inclined to think that facts called to our attention when we first studied a subject were self-evident and had been known by those interested in the subject since time immemorial. But advances in the natural sciences are usually made by the observation for the first time or the correlation of "facts" that have been "evident" since man had eyes to see. The following extract (Geikie, 1905, pp. 318-322) shows how Sir James Hall proved for the first time a principle that is now one of the bases upon which we classify igneous rocks—namely that the rate of cooling of a magma influences the texture of the rock finally formed; and how the same man applied his experimental evidence to prove yet another point. Hutton's system, referred to in the quotation, was founded upon his belief that rocks such as granite and basalt were formed when molten rock-matter was intruded into older rocks or flowed out upon the Earth's surface and there cooled and hardened:

> As his objections diminished, Hall's interest in the details of the system increased. His practical mind soon perceived that some of the principles, which Hutton had established by reasoning and analogy, might be brought to the test of direct experiment. And he urged his friend to make the attempt, or allow him to carry out the necessary researches. The proposal received little encouragement from the philosopher. Hutton believed that the scale of Nature's processes was so vast that no imitation of them, on the small scale of a laboratory, could possibly lead to any reliable results, or as he afterwards expressed himself in print, "there are superficial reasoning men who, without truly knowing what they see, think they know those regions of the earth which can never be seen, and who

judge of the great operations of the mineral kingdom from having kindled a fire and looked into the bottom of a little crucible."[1]

Sir James Hall, notwithstanding his veneration for his master, could not agree with him in this verdict. He was confirmed in his opinion by an accident which had occurred at Leith glass-works, where a large mass of common green glass, that had been allowed to cool slowly, was found to have lost all the properties of glass, becoming opaque, white, hard and crystalline. Yet a piece of this substance, when once more melted and rapidly cooled, recovered its true vitreous characters. Hall's shrewd instinct at once applied this observation to the Huttonian doctrine of the igneous origin of granite and other rocks. It had been objected to Hutton's views that the effect of great heat on rocks was to reduce them to the condition of glass, but that granite and whinstone, being crystalline substances, could never possibly have been melted. Yet here, in this glass-house material, it could be demonstrated that a thoroughly molten glass could, by slow cooling, be converted into a crystalline condition, and could be changed once more by fusion into glass. Hutton had overlooked the possibility that the results of fusion might be modified by the rate of cooling, and Hall at once began to test the matter by experiment. He repeated the process by which the devitrified glass had been accidentally obtained at the glass-house, and found that he could at will produce, from the same mass of bottle glass, either a glass or a stony substance, according to the rate at which he allowed it to cool.

Sir James was too loyal a friend and too devoted an admirer of the author of *The Theory of the Earth* to pursue these researches far during the philosopher's lifetime. "I considered myself as bound," he tells us, "in practice to pay deference to his opinion, and I abstained during the remainder of his life from the prosecution of experiments which I had begun in 1790."[1]

---

[1] *Theory of the Earth,* vol. I, p. 251.

The death of Hutton in 1797 allowed the Laird of Dunglass to resume the experiments on which he had been meditating during the intervening years. Selecting samples of "whinstones," that is, intrusive dolerites and basalts, from the dykes and sills in the Carboniferous strata around Edinburgh, he reduced them in the reverberatory furnace of an iron-foundry to the condition of perfect glass. Portions of this glass were afterwards re-fused and allowed to cool very slowly. There was thus obtained "a substance differing in all respects from glass, and in texture completely resembling whinstone." This substance had a distinctly crystalline structure, and Hall gave it the name of *crystallite,* which had been suggested by the chemist, Dr. Hope.

Before he was interested in the defense of the Huttonian theory, Sir James had made a journey into Italy in the year 1785, visiting Vesuvius, Etna, and the Lipari Isles, and having for part of the time the advantage of the company of Dolomieu. He could not help being much struck with the resemblance between the lavas of these volcanic regions and the familiar "whinstones" of his own country. So close was this resemblance in every respect that he felt "confident that there was not a lava in Mount Etna to which a counterpart might not be produced from the whinstones of Scotland." At Monte Somma he noted the abundant "vertical lavas" which, in bands from two to twelve feet broad, run up the old crater-wall. These bands seemed to him at the time "to present only an amusing variety in the history of volcanic eruptions," and, like Dolomieu and Breislak, he looked on them as marking the positions of rents which, formed in the mountain during former volcanic explosions, had been filled in from above by the outflow of lava down the outer fissured surface of the cone. Subsequent reflection, however, led him to reconsider this opinion, and to realize that these "vertical lavas" were "of the utmost consequence in geology, by supplying an intermediate link between the external and subterraneous productions of heat. I now think," he remarks, "that though we judged rightly in believing those lavas to have flowed in crevices, we were mistaken as to their direction; for instead of flowing downwards, I am convinced they have flowed upwards, and that the crevices have performed the office of pipes, through which lateral explosions have found a vent." He had observed, also, that the outer margins of some of these dykes, in contact with the surrounding rock, were vitreous, while the central parts presented the ordinary lithoid texture. This difference, he saw, was fully explained by his fusion experiments. The lava having risen in a cold fissure, and having been suddenly chilled along its outer surface, consolidated there as glass, while the inner parts, which had cooled more slowly, took a crystalline structure.

---

[1] For Hall's papers see Trans. Roy. Soc. Edin., iii. (1790), p. 8; v. (1798), p. 43; vi. (1812), p. 71; vii. (1812), pp. 79, 139, 169; x. (1825), p. 314.

These observations are of historic interest in the progress of volcanic geology. Hall had sagaciously found the true interpretation of volcanic dykes, and he at once proceeded to apply it to the explanation of the abundant dykes of Scotland. He thus brought to the support of Hutton's doctrine of the igneous intrusion of these rocks a new and strong confirmation from the actual crater of a recent volcano.

Practical Uses of Rocks

Rocks have practical as well as scientific uses. From the natural hollow in the rock, the cave of prehistoric times, to the elaborate buildings of the historical period, man has used rocks to shelter him. They are used to construct roads and bridges as well. They furnish material for ornamental purposes, statues, and monuments, and the ground-up fragments of various rocks are made into plasters, cement, and concrete.

In the following quotation (Jones and Whittlesey, 1925, pp. 262-263) some of the uses of stone are summed up:

Building Stone

Stone has been used for building purposes throughout the ages. Building stone should possess as many as possible of the following qualities: (a) ease of cutting and shaping, (b) attractive appearance, (c) resistance to weathering and other wear, (d) permanence of color, or at least no tendency to stain when exposed to the weather, and (e) strength in sustaining weight. No stone possesses all of these qualities. In selecting stone for a particular use builders balance points b, c, d, and e against a. Passing styles have a great deal to do with the favor in which a particular stone is held, with the result that the value of certain quarries has risen and fallen sharply with changes in fashion.

Granite is difficult and costly to work, but it is very durable, and certain colors and textures of it are in demand for the street level portions of large buildings in cities. Limestones and sandstones vary widely in quality. The most prized limestone now used in the United States is that from the Bedford District of Southern Indiana. Bedford limestone is soft and very easy to saw and carve as it comes from the quarry, and its texture is smooth and its color a pleasing gray or blue-gray. Exposed surfaces of this stone harden with time and become very durable, and do not stain. Many limestones become streaked or spotted when exposed to the air. Most sandstones weather quickly, and their use for building purposes has therefore declined. Many once fashionable quarters of the Atlantic Seaboard cities were constructed of brown stone, a variety of sandstone, and many public and semi-public buildings in the Middle West were built of red sandstone in the decades preceding 1900. Marble, which is an aristocratic and distant cousin to the common limestones, has special uses for fine interior finish and for a very few exteriors. Caen marble, of which many famous French chateaux and churches are built is one variety widely used for exteriors, but it more closely resembles Bedford limestone than high-grade marble. Shale is too soft to be of value for building stone; conglomerate is difficult to shape properly; quartzite is so extremely hard as to be almost unworkable; most of the fine-grained igneous rocks are too hard to work satisfactorily. Glacial bowlders are striking because of their variety of shape, size and color. Their use generally is confined to small structures.

Mineral Building Materials Other Than Stone

Whereas all peoples have lavished their labor, their wealth, and their ingenuity in constructing edifices of stone, ordinary buildings generally have been made of the humbler materials almost universally distributed throughout the earth's crust. Of these clay is most widely used, either in the form of sun-dried mud, known in many parts of the world as "adobe," or hardened by burning into brick or tile. Deposits of the requisite quality are common in most types of residual soils, in old alluvial soils, and in till. A special type of brick or tile, called terra cotta, is widely used for the facing of buildings because of its polished surface and its resistance to weather.

Within the past generation the art of making cement has been perfected. Prepared from limestone or from slag produced in the making of steel, cement serves to bind sand or gravel into hard rock called concrete. If set about a core of steel, concrete has not only the capacity to resist crushing, common to all rock, but also great tensile strength. These qualities, coupled with cheapness, the ease with which constituent materials may be transported, and the limitless variety of forms into which it may be cast, have brought concrete into favor for pavements, foundations, walls and floors, bridges, dams, breakwaters and piers, canal linings, and many lesser uses.

Sand, besides being a component of concrete, is the basis of the glass-making industry.

BIBLIOGRAPHY

Chapter I—Minerals and Rocks

Sir Archibald Geikie, *The Founders of Geology*. London: The Macmillan Company, 1905, pp. 318-322.

W. D. Jones and D. S. Whittlesey, *An Introduction to Economic Geography*. The University of Chicago Press, 1925, vol. 1, pp. 262-263, 267.

E. H. Kraus and E. F. Holden, *Gems and Gem Materials*. New York: McGraw-Hill Book Company, 1925, pp. 1-2 (Introduction), 3-4 (Introduction), 87-88, 89-90, 91-93, 95-97, 103-104.

H. P. Whitlock, *The Story of the Minerals*. American Museum of Natural History, Handbook Series No. 12, New York, 1925, pp. 10-11, 17-20, 37-41.

CHAPTER II

CLIMATE; WEATHERING AND SOILS

Climate

It is natural to think of climate as affecting the plants and animals that inhabit a region but its effect on geological processes, though just as marked, is not so generally recognized. A desert is not only a region of barren mountains and valleys, or a waste of shifting sand with a minimum of living beings peculiar to the environment; it is also a place where stream action is reduced nearly to the vanishing point, where surface wash accompanying the occasional heavy showers reaches its greatest activity, and where the wind, unhindered by vegetation, blows the loose sand into dunes, drives it with cutting force against all obstacles, and whirls the dust away, sometimes to great distances. On the other hand, a tropical forest is a region where rain wash and wind work lose much of their erosive power, but where decay cuts deeply into the rock, ground water dissolves and carries away great quantities of matter, and the swollen streams carry their load through to the sea.

The land forms developed under each climatic environment are characteristic and peculiar, and they must have been equally so in the past. The sediments deposited in a desert three hundred million years ago must have differed as much from the glacial deposits or the stream débris of moist areas as they do to-day. The ancient animals and plants were not those of the present but they showed the same adaptation to their climatic environment as do their living descendants. For this reason climatic conditions have left an indelible imprint upon the geological record, and a study of the geological result and the adaptations of organisms to-day enables us to interpret similar results and adaptations in the past and thus to write the history of the ages that are gone.

The climates of no two regions in the same latitude are quite the same. The climate of Antarctica differs from that of the Arctic Ocean, though each includes a pole of the Earth, because the former is a vast continent and the latter an extensive sea. Greenland, relatively distant from the pole, is more nearly like the Antarctic continent and both these areas exert an influence upon the storms of their respective hemispheres that is only now being appreciated and studied.

The Trade Wind zones of the Earth are the loci of most of the great deserts. The actual rainfall in these deserts varies from place to place and from year to year, but the most consistently rainless of all lie along the west coast of South America from the equator to 30° south latitude. The southeast Trades are robbed of their moisture by the towering Andes and descend upon that region as hot, dry winds. The southwesterlies blowing from the Pacific pass from a cold current of water to a hot land; so they also bring little rain. Yet even in such regions rain does fall. The Desert of Atacama in Chile may be rainless for years together, yet in 1925 peculiar weather conditions resulted in phenomenal rains. The surface of the land suffered rapid erosion, and deep valleys were formed where none existed before.

Isaiah Bowman (1924, pp. 40-41), writing before the rains of 1925, described the normal conditions in the South American deserts, and the effects of abnormal rainfall as follows:

Rainfall of the Desert

The coast of northern Chile is quite the driest of which there is any record in the world. For a 21-year period Iquique has an average rainfall of 1.5 mm. (0.6 inches), and Arica (for a 19-year period) has still less, 0.6 mm. But an average in the desert is as nearly useless a computation as even the desert affords. There is no such a thing as a normal desert rainfall. Years of absolute drought pass, and the foreigner who comes out on a three-year or a five-year contract may stay his time and depart without having known a drop of rain to fall; and he may even assert that it never falls and speak as one who knows because he "has lived there." The British Consul at Iquique told me that he had advised some of his friends who were coming out from England not to bring umbrellas, for in the fourteen years that he had then known the coast no rain had fallen. Yet on the night on which they disembarked from the steamer it was raining hard. In 1906 there was a three days' rain, a succession of light showers with intervals of heavy mist, which penetrated the houses and collected and ran off walls and ceilings and soaked the carpets and beds. It is only the rare downpour that gives Iquique anything at all to average throughout the years. It is as nearly like a rainless land as any that we know on the earth to-day.

Exceptional Rains and Floods in the Nitrate Desert

Yet it must be impressed that rains actually do occur at intervals in the Desert of Atacama and that some of them are of extraordinary character. The reason for their occurrence is not quite clear. In the Cordillera of the Andes and the western foothills periodic summer rains fall as far down as 8,000 or 10,000 feet, lower still in some places, higher up in others. At long intervals the usual rains may be supplemented by an extraordinarily heavy snowfall or an equally heavy rainfall. The sudden precipitation of rain in unusual quantities is a feature of practically all the deserts of the world. In northern Chile the rains and snows produce heavy floods that extend far out over the nitrate pampa and freshen the innumerable gullies that feed the main streams and spread vast sheets of mud and gravel over the outer piedmont. They are said to occur once or twice in a lifetime.

The Desert of Tarapacá

It might appear that such deserts are utterly valueless, but the Desert of Atacama contains the richest deposit of nitrates in the world. The exact manner in which they were formed is still in doubt, but we know that it depends fundamentally upon the aridity of the region and that increased rainfall with through-flowing streams would soon dissolve and wash away the valuable salts. Bowman (1924, pp. 62-63) describes the nitrate region in the Desert of Tarapacá as follows:

The Desert of Tarapacá contains rich nitrate deposits that have been worked for half a century and upon which is based the prosperity of the city of Iquique and several neighboring ports engaged in the nitrate business. Before the discovery of nitrate it was an almost uninhabited region. Towns, railways, and nitrate works have been made out-of-hand. . . . The nitrate deposits are found along the line of a great depression, the continuation northward of the well-known "longitudinal valley" of Chile. The Coast Range rises abruptly several thousand feet above the sea, and between its moderate eastern slopes and the great western wall of the Andes is a depression with no outlet to the sea. The extreme smallness and infrequency of the rainfall have already been discussed. As we have said more than a decade may pass without a single shower. Up in the mountains, however, the snow falls every winter, sometimes in local storms, sometimes over a vast area and reaching down to eleven and twelve thousand feet on the western mountain flanks. There are also rather frequent summer showers above eight and ten thousand feet. From these two sources the mountain streams derive their water supply and come down through steep-walled canyons to the great, broad-spreading alluvial plain at the western foot of the mountains. The streams have lost volume in their descent over the waste-strewn floors of the canyons and by evaporation, so that they reach the border of the piedmont as trickling brooks rather than as powerful mountain torrents. Whatever of land waste they have carried along with them to the mountain border is here deposited, so that there is a steady building-up on the outer or western fringe of the piedmont from year to year.

When there are unusually heavy mountain snows and rains the streams reach the border of the desert in greater volume and spread their mantle of waste over many square miles of the desert, and in rare years of extraordinary rain and snow the streams may come down in such volume as to flow out over the nitrate pampa, as they did in 1906 when they flooded the pampa as far as the railroad line near the western border.

Were these rare floods more frequent in occurrence, lakes would be formed and there would be outlets to the sea and the nitrate would be dissolved and washed away. It is the very dryness of the climate and the infrequency of the floods that make it possible for the nitrate to remain.

Evidence for Climatic Changes

Since fossils began to be studied in the light of what they truly represent—that is as remains of the life of the past—geologists have recognized that the climate of any given region has not always been as it is to-day. Coral reefs in the ancient rocks of northern Greenland, where to-day the waters are too cold to support them—coal seams in the snowy mountains of Spitzbergen where no vegetation can now grow—these and many other such occurrences put the fact of climatic changes beyond reasonable doubt.

The evidence for these changes has always been there but we have only recently learned to read it correctly. The first result of such studies was the notion that a warm, moist, uniform climate in early geological times had slowly given way to the variable, zoned climate of to-day. Then came the recognition of widespread glacial climates in the recent past. This in turn was followed by the recognition of older periods of glaciation, one of them in Permian times and located in the present subtropical regions of Australia, India, and South Africa, until it has become evident that no continual, definite change has taken place but that diverse climates have succeeded each other.

We know these past climates by their results. The life that flourished under their dominion gives us a clue, the sedimentary deposits tell us much, but the shaping of the land surface itself by the agents of erosion—so dependent upon the climate—can also reveal the past. Albrecht Penck (1905, pp. 165-172) wrote about this evidence as follows:

> . . . Running water produces long and extensive slopes by its erosive and constructive force; it is enabled to transform slopes caused by crustal movements into others which show a perfect adjustment to the material of the earth's crust; and

finally it wears the land down to gently sloping surfaces of the highest resistance. Running water also deposits material in the form of gently sloping plains, which extend very far. The action of running water is therefore both a degrading and an aggrading one, and the grades which it forms show a systematic arrangement; they slope down in the direction in which the water moves, mostly towards the sea; . . .

Glacial action also produces slopes, either due to erosion or to accumulation, but these slopes do not show such a systematic arrangement as the grades of fluviatile origin. Glacial action does not impose on the land the continuity of its surface slopes as running water does; it produces irregularities in its bed which not only show continuous slopes but often opposite and reversed slopes. Wind also produces slopes, but their arrangement is still more irregular than those of a glacier bed. There is a sharp limit between the regions of glacial erosion and of glacial deposition; the forms of eolian erosion and eolian deposition also occur in close proximity; wind does not transport so continually nor so far as running water and glaciers do; its action is more brief and unsteady. Thus, the arrangement of the slopes of the land surface permits us to recognize fluviatile, glacial and eolian forms.

Now the action of running water and of glaciers and the display of eolian forces depend on climate; rivers exist only where a part of the rain runs off superficially on the land; their morphological action depends, therefore, on the amount of run-off, which is consequently a geomorphological factor of great importance. Glaciers are formed only where the amount of snowy precipitation surpasses that amount which can be melted away by the action of the sun. Wind action finally becomes very visible, and is exclusively performed where neither water nor ice action occur. We see, therefore, that the difference between precipitation and evaporation on one side and between snowfall and ablation on the other, determine the surface features of the land, and hence we can recognize in the surface features of the land certain features of its climate in the same way as in its covering with vegetation.

. . . .

We see on the earth's surface not only the features of the present climate but also those of a past climate. Very extended areas, formerly covered by ice, are now exposed to river action. The basins formed by the meeting of normal slopes and those reversed slopes which originated under the ice, are filled with water and form lakes; the river action has not reached a normal slope; waterfalls interrupt their courses. These lakes and waterfalls are indications of extreme youth of river action over large areas, and at the same time they are as significant morphological evidences of recent climatic change as moraines and rock striations are in the geological sense. In mountain regions, as for example in the Alps, the lakes occupy valleys which have the arrangement of river valleys; they are subordinate to an older topography, formed by fluvial action, and we can recognize in the valleys of the Alps not only one climatic change, but a succession of those changes. In the lowlands of the north, however, it is nearly impossible to trace the features of an older topography under the glacial one. This, however, does not show those signs of antiquity which we might expect to find in regions of continual glaciation. Hence we must infer that the glacial features of other northern lowlands are also superposed on an older topography which has been destroyed in its characteristic features. We see on the border regions of the old glaciations moraines which have totally lost their morainic forms, and already possess the surface features of a mature fluviatile topography. These surface features have long ago led to the conclusion that we have to deal here with older moraines, which indicate an older climatic change. Thus regions of river degradation indicate climatic change by their composition as well as glaciated regions indicate such change by their forms.

We meet with proofs of climatic changes also in desert regions. Investigations of American geologists, especially of

Gilbert and Russell, have shown that the region of Great Salt Lake was once occupied by a far larger freshwater lake, the shore lines of which can be easily followed and the outlet of which can be recognized in a side valley of Snake River. We can trace in the Sahara very extended river valleys from the Highland of Ahaggar down to the region of the south Algerian Shotts. These valleys cannot be compared with those short wadies in which the water of cloudbursts rushes down. They indicate a former moister climate; the desert with its surface features extends here over a region of former water action in the same way as, farther north, river action is now displayed on a surface formerly covered by glaciers.

In the interior of two continents we finally meet with surface features which might be taken for morphological indications of a change of desert climate into a moister one. Three large lake basins interrupt the general grades of the head waters of the principal African rivers. In the region of the Zambesi river we find the very deep Lake Nyanza, in the catchment basin of the Congo the likewise deep Lake Tanganyika, and along the upper branches of the Nile the Victoria Nyanza. There are good evidences that the two first named lakes occupy depressions formed by crustal movement. Now we have seen that generally crustal movements, however profound they may be, do not interrupt the formation of slopes of degradation. Why did such interruption occur in central Africa? In order to give an answer, let us consider how the formation of isolated basins by crustal movement is hindered in the regions of fluviatile drainage. A tract of land, sinking down, is filled up by sediment during its subsidence; thus the rivers maintain their slopes and the formation of closed basins is counteracted. Elevations occurring in river basins are often cut through by rivers during their elevation, and then they will not transform neighboring regions into closed basins. The formation of those basins by crustal movement will occur only when the rivers in the disturbed regions are too feeble to fill up the sinking regions and to cut through the rising chasms. The central

African great lakes are located in the neighborhood of insignificant river action. East of them extend the dry plateaus of German East Africa. Here crustal movement has produced many closed basins called Gräben (tectonic troughs) by Suess. Many of these Gräben are empty, or filled only at their bottoms with soda-lakes; others are nearly filled, as for example, Lake Rudolph. A slight climatic change would fill the basin of this lake so that its waters would overflow in wet years. This is the case with Lake Tanganyika. Its outlet, the Lukuga, flows only in wet years; in dry years the great lake is without outlet. A stronger climatic change would transform Lake Rudolph into a normal freshwater lake with permanent outflow. This type of lake is represented in the neighborhood by the Victoria Nyanza, by the Albert and Albert Edward Nyanza, and farther south by Lake Nyassa. We can understand best the existence of the large freshwater lakes of east equatorial Africa by assuming that their water drowns basins formed in a dry climate, such as prevails farther east. It is very significant that these great lakes occur in a region of transition between the dry and the wet tropical climate, a region which would be affected very much by climatic changes. The same is true for Lake Baikal in eastern Siberia. It belongs to a zone of great inland lakes at the northern border region of the central Asiatic deserts. Three of these lakes have salt water; two of them are so large that they are called erroneously seas, namely Lake Caspian and Lake Aral; the third is the shallow lake Balkash. An increase of precipitation over Russia would cause a raising of the level of Lake Caspian and an extension of its surface, and if on this larger surface evaporation would not balance the increased inflow, and establish thus a new equilibrium, then the lake will overflow in the Manich Valley and would be changed in the course of time into a freshwater lake. On the other hand, if the desert region of Mongolia should extend, the principal affluent of Lake Baikal would become smaller, and a moment would arrive when the quantity of water running into Lake Baikal would be totally balanced by the evaporation going on there. Then this lake would lose its outlet, and the salts brought by its affluent would gather in its basin, and it would be transformed into a salt lake. Such rather light climatic changes would transform the salt lakes of the northern border regions of the central Asiatic deserts into freshwater lakes, or the large freshwater lake into a salt lake. We can understand best the existence of these lakes by the working hypothesis that their basins were formed originally in a dry climate, where river action could not neutralize transformation by crustal movement, and that they thence were more or less filled with water, according to the actual climate of their region. In this way we are disposed to recognize also in the great freshwater lakes in the interior of some continents morphological witnesses of climatic changes.

If we now look over the whole set of evidence, we see morphological traces of glacial action in countries which are now drained and shaped by running water, and recognize in mountain chains, as for example the Alps, traces of river action preceding this glacial action. We follow traces of extended river action into the desert, and we find forms which were probably produced in a dry climate, with no run-off, in regions which are now subject to river action. The climatic features of the land surface indicate that climatic changes are not only in one direction; we cannot say that the climate of the land is becoming dryer and dryer, or less and less glacial; they reveal continued climatic oscillations.

Recent Climatic Changes

Are these climatic changes a thing of the past or must we look forward to ever-shifting climates in the future of civilization? The time that has passed since the dawn of history is so short, and the period during which scientific records have been kept so small a fraction of even that time, that the question is difficult to answer. Students of climate warn us against the popular notions of changing climate in our day, notions based upon a few dry, or cold, or warm seasons. But the archeological study of past civilizations and of the migrations of races, examination of the growth rings of the big trees of California, the records of harvest dates in Europe, the waxing and waning of lake waters recorded in history or upon the shores of those lakes, and other types of evidence, lead us to conclude that climates are no more fixed to-day than in the past, and that imperceptible changes are even now in progress.

Some of this evidence gathered in southwestern North America and in Central America is considered below (Brooks, 1922, pp. 149-153):

> The question of climatic changes during the historic period has been the subject of much discussion, and several great meteorologists and geographers have endeavoured to prove that at least since about 500 B.C. there has been no appreciable variation. It is admitted that there have been shiftings of the centres of population and civilization, first from Egypt and Mesopotamia to the Mediterranean regions, and later to northern and western Europe, but these have been attributed chiefly to political causes, and especially to the rise of Islam and the rule of the "accursed Turk." Recently, however, there has arisen a class of evidence which cannot be explained away on political grounds, and which appears to have decided the battle in favour of the supporters of change; I refer to the evidence of the trees. . . . The conclusions derived from the big trees of California have fallen admirably into line with archæological work in central America, in central Asia and other regions, and have shown that the larger variations even of comparatively recent times have been very extensive, if not world-wide, in their development.
>
> Let us consider first the evidence of the trees. These indicate that after the moist period ending about A.D. 400, . . . the rainfall was generally light until about A.D. 1000, when it showed a sharp rise, probably to the level attained in A.D. 1. (The correction for age renders an exact comparison between periods a thousand years apart difficult.) This period of abundant rainfall lasted some fifty years, followed by a gradual decline to a brief minimum, shortly before A.D. 1200.

About 1300 occurred another rapid rise, reaching a maximum before 1350; the period of heavy rain continued a short while after 1400, when a decline set in, reaching a minimum at 1500, after which the rainfall recovered somewhat, and subsequently maintained approximately its present level, with a slight maximum about 1600 to 1645.

In the desert of Arizona, in regions at present too dry for agriculture, there are abundant ruins, which are attributed by Huntington to three periods:

(a) Pueblo ruins, dating back to just before the coming of the Spaniards (i.e., about A.D. 1600), and indicating merely an increase of population at the present centres.

(b) Ruins of an older civilization, termed by Huntington the Pajaritan, during which numerous inhabitants lived in places where at present no crops can be raised. "These people, as appears from their pottery, their skulls and their methods of agriculture, belong to a different civilization from that of the modern Pueblas who inhabited Gran Quivera at the time of the coming of the Spaniards. They had evidently disappeared long before that date, as is evident from the present ruins of their villages, and from the absence of any hint of their existence in the early annals of the country" (*Geogr. Journal,* 40, 1912, p. 396).

The largest ruins of this type invariably lie near the main lines of drainage. They consist of villages with houses of several storeys. But digging down beneath these ruins we find (c) traces of an older occupation, and ruins of a primitive type are also found on the plateaus remote from any except small valleys. "They are usually small, and are greatly ruined, and seem to belong to a time long anterior to the main large ruins." Huntington terms this type the Hohokam; unfortunately this and the Pajaritan occupations cannot be accurately dated, but it is reasonable to connect them with the rainfall maxima shown by the trees, about the time of Christ, and in A.D. 1000 to A.D. 1300.

A similar succession has been found in the neighbourhood of Mexico City. The earliest trace of occupation is a crude "mountain pottery," in ordinary river sand and gravel. These deposits are succeeded by finer sand with better pottery known as the "San Juan" type, above which comes a culture layer with the remains of houses. This is covered by a bed of "tepetate," a white calcareous deposit frequently found in dry regions where much water evaporates. The gravels suggest the occasional heavy rains of arid countries. The San Juan pottery extends throughout the "tepetate," which probably corresponds to the dry period of A.D. 400-1000 in California.

Historical records in Mexico date back to the coming of the Aztecs in A.D. 1325. They show that in 1325 and again in 1446 the level of the lake of Mexico was high, but towards the end of the fifteenth century the water was much lower. In 1520 it was high again; in 1600 it was low, but high from 1629 to 1634. From 1675 to 1755 was a long dry period. On the whole the climate from 300 to 600 years ago seems to have been moister than that of to-day.

Still further south in the Peninsula of Yucatan recent explorations have yielded results of extreme interest. Yucatan lies within the tropical rain-belt, and is covered by almost impenetrable forests. The climate is enervating and unhealthy, and the present inhabitants are greatly lacking in vigour. In the forest, however, have been found the ruins of ninety-two towns, some of them of great size, and all remarkable for the beauty as well as the solidity of their architecture.

These ruins belong to the great Mayan civilization. Mayan history has been briefly summarized by Huntington as follows: "First we have a long period of active development, during which the calendar was evolved and the arts of architecture and sculpture were gradually developed. . . . This time of marked growth must have preceded the Christian era. Then comes . . . the building of the great cities of Copan, Quirigua, Tikal and others. These first great cities were in the southern part of the Maya area, on the borders of Honduras or in eastern Guatemala. They lasted perhaps three or four centuries; then quickly declined. So far as we have any evidence, civilization never revived in this southern area, for the structures of the great period have not been rebuilt by later inhabitants. Towards the end of the period of greatness the centre of Mayan culture moved northward. . . . The great period, according to Bowditch, lasted from 100 B.C. to A.D. 350 . . . then came a time of very low civilization, lasting for centuries. . . . A revival ensued about A.D. 900 or A.D. 1000, and architecture once more reached a high pitch, but . . . only in northern Yucatan; all the rest of the country seems to have remained in darkness. Moreover, this mediæval revival was relatively short-lived. Since that time the condition of the Mayas has fluctuated more or less, but on the whole there has been a decline."

Now at the present day the densest and most progressive population in Yucatan is found in the driest part of the country, where the forest gives place to jungle. If the line of separation between jungle and forest were moved southward 300 miles, the former would include all the districts where ruins are now found. We see from the above summary that the prosperous periods of Mayan history were just those periods which in California were moist; in Yucatan they must have been dry. Huntington's explanation is the theory of the "shifting of climatic belts"; during the rainy period in California the temperate storm-tracks were shifted further southward. At the same time the sub-tropical high-pressure belt, which at present lies over the West Indies, was also shifted southwards, and this brought a dry cool winter to Yucatan, with an increased contrast of seasons, and consequently a more invigorating climate.

The Evidence from Asia

The following quotations from Ellsworth Huntington's *The Pulse of Asia* trace clearly the changes recorded in the desert basins of central Asia and indicate how climate may have affected the development and the migrations of the human race. It is a picture that leads one back into early human history—perhaps beyond—but the true perspective is gained only by substituting the term "recent geologic" for "early human." Then we see a record of climatic changes in the present perhaps as great, when their consummation is attained, as any that have happened in the past (Huntington, 1907, pp. 6-9, 277-279, 280-283, 292-294, 356-358).

From the Caspian Sea on the west to Manchuria on the east, Central Asia is largely a country of deserts. It is politically divided into the countries of Persia, Afghanistan, Baluchistan, northern India, Tibet, China, and Asiatic Russia. It varies in elevation from the low depression of the Caspian Sea and the small basin of Turfan, lying three hundred feet below sea-level in the very heart of Asia, to the plateaus of Tian Shan, Tibet, and the Pamirs at an elevation of from 10,000 to 20,000 feet above the sea. Although usually the mountainous parts are comparatively rainy and are often well covered with vegetation, the lowlands, which comprise most of the country, are intensely dry and almost absolutely desert. The people are equally varied, the fierce Afghan being as different from the sycophant Persian, as is the truculent Mongol from the mild Chanto of Chinese Turkestan. Yet in spite of all this, not only the physical features of the country, but the habits and character of its inhabitants, possess a distinct unity; for all alike bear the impress of an arid climate.

Central Asia, more fully perhaps than any other part of the world, exemplifies the great geographic type in which the topography, vegetation, animal life, and human civilization have developed along the lines characteristic of prolonged aridity. We all know something of arid countries, empirically or from observation. We need, however, a more general concept, so that the term "arid" shall bring to mind the essential features of a definite geographic type, just as the term "bovine" brings to mind the spreading horns, large eyes, heavy body, cloven hoofs, cud, and other essential features of a definite zoölogic type. If once the geographic type is well understood in its highly developed form in Central Asia, it will be easy to comprehend how similar conditions of climate in other parts of the world give rise to similar topographic features, and how the two combine to determine the distribution and nature of life of all forms.

The rainfall of Central Asia is so small that the rivers fail to reach the sea. Hence the whole of a vast region stretching three thousand miles east and west, and having an area nearly equal to that of the United States, is made up of enclosed basins, from which there is no outlet. Each consists essentially of a peripheral ring of higher land,—usually mountainous, but sometimes merely a broad, gentle arch,—within which a desert plain of gravel, sand, and clay, brought from the mountains by rivers, surrounds a salt lake, or the saline beds whence the waters of an ancient lake have evaporated. Where the peripheral ring of higher land is at all mountainous, it is flanked, and often half buried, by vast slopes of barren rock-waste—typical piedmont deposits of gravel, washed out from the uplands by floods. Because of the aridity, vegetable life is scanty except along the courses of streams and in the rainy plateaus. Far less than a tenth of the country is permanently habitable: the rest is either absolute desert, or mitigated desert which supports vegetation part of the year, but is too dry among the plains, and too cold among the mountains, to allow permanent occupation. Hence the inhabitants must either live in irrigated oases along the rivers, or wander from place to place in search of pasture for their flocks. There are no manufacturing communities, either large or small; no commercial centres except local bazaars; and no continuous agricultural population, such as that of the Mississippi Valley, dependent on rain for its water supply. Two main types of civilization prevail: the condition of nomadism with its independent mode of life, due to the scattered state of the sparse population, and the condition of intensive agriculture in irrigated oases with its centralized mode of life, due to the crowding together of population in communities whose size is directly proportional to that of the streams. Because of the arid climate and the consequent physical characteristics of Central Asia, its types of civilization have been, are, and probably must continue to be fundamentally different from those of well-watered regions such as most of America and Europe.

The Dry River and the Dry Mountains

For Kuruk Tagh and Chol Tagh as a whole I cannot do better than quote from Abdur Rehim, the guide of Kuzzil Singer. My own limited observations agreed entirely with his. Abdur Rehim was a tall, lank hunter, who for the forty years of his life had lived in the desert, far from all neighbors except his brothers. He knew every mountain, plain and spring within a hundred miles of his home, and every spot where a little vegetation flourishes, or rather perishes, in a damp spot surrounded by salt. His lonely life, and his long, hard journeys after game had given to him, as to his brothers, a degree of energy and self-reliance which I have never seen equaled in Central Asia. And more than this, he was a man who, though he talked but little, thought deeply.

"In old times, were the springs larger or smaller than now, or were they just the same?" I asked him one day.

"Larger," he answered without hesitation; and when I questioned why, he went on, without prompting or further questioning, to say:—

"When I was a boy and first went with my father to hunt, or to care for sheep, all the springs were larger than now. Where they now flow a quarter of a mile, they then flowed half. Reed-beds that are now a foot high were then two, and there were more of them. And there were more wild animals; we saw three or four then for one now. I think it must be because there is less water. It used to rain hard enough to form running streams six or seven times a year, and now it does so only two or three."

After speaking thus of the decrease in rainfall during the past four or five years, without taking due account of the difference between the impressions of a boy and of a man, he went on to something more important and reliable.

"And long, long ago, before the time of my grandfathers, perhaps in the days of the old forts at Ying-pen and Pochinza, there must have been much more water. In the high mountains there are many places where little stone shepherds' huts, with the roofs all fallen in, stand in valleys where nobody has ever known of there being any water. And all around them are the droppings of cattle. The nearest water is sometimes five or ten miles away. Surely nobody would ever build a house in such a place. So I think there must have been running water in the valleys when the houses were built. How many such houses have I seen? Oh, many. I never counted, but the mountains are full of them.

"And then, away from the great mountains there are dry springs everywhere, places where the salt deposit of a spring and a few reeds can be seen. No one has ever known of there being any water in these places, but from every side old paths of camels and antelopes come in, just as they do to places where there is always water. The animals used to come to the dry springs regularly to drink. Now, nothing ever visits them except a stray animal once or twice a year to eat the few reeds. Near almost every one of the dry springs there are little shelters made of rocks and tamarisks, just such as we make now when we lie in wait for game. Nobody would make those beside a dry spring. They were made long ago: we don't know by whom.

"Nobody ever asked me about this before, and I have never talked of it. But I have seen many things when I have been hunting, and have thought about them. So,"—according to the Turki idiom,—"that's what I know in my stomach."

The Waxing and Waning of Lop-Nor

In traveling through the Lop basin we have everywhere found evidences of pronounced changes of climate during historic times. It will now be well to sum up the evidence, and to ascertain how far the conclusion which we have reached is in accordance with the phenomena of Lop-Nor. The most widespread proof that there have been climatic changes during the last two or three thousand years is found in the death of vegetation over large areas. On the lower slopes of the Kwen Lun Mountains the dissected condition of deposits of loess shows that a cover of grassy vegetation prevailed at no remote time, but has now died. In the zone of vegetation, for a distance of seven hundred miles, plants of all kinds show signs of drying up: the tamarisks usually stand upon mounds; the poplars are dead or dying except in the moistest places; and beds of dead reeds cover scores of square miles. It has often been asserted that in many parts of the world the destruction of forests has been the cause of a diminution of rainfall. In the Lop basin, it is manifest that the opposite has been true: a diminution in the water supply has been the cause of the destruction of forests. Another line of evidence shows that ancient roads such as that from Keriya northward, or the great trade route through Lulan, have been abandoned because there is now no water along them. Again, in the Dry Mountains and elsewhere, springs once frequented by animals or by men have now disappeared. Both to the north and south of the Lop basin, regions which once were the home of nomadic shepherds are now uninhabited because there is not enough water and grass.

When we turn to the rivers, it appears that in the seven hundred miles from Khotan eastward, seventeen are worthy of notice by reason of their size or because they support oases. Of the seventeen all but four come to an end in the zone of vegetation, and hence it is impossible to determine whether they have diminished in length. The remaining four all once flowed from eight to twenty-five miles farther into the sand than they now do, as appears from dead vegetation. Thirteen of the seventeen rivers have on their lower courses the ruins of towns dating from the Buddhist era, a thousand or more years ago. In almost every case, the ancient towns were larger than their successors, this being notably true of Niya, Yartungaz, Endereh, Cherchen, Vash Sheri, and Miran. And, finally, with the possible exception of old Cherchen, Charklik, and Karadong on the Keriya River, the older ruins are situated so far out in the desert, or upon rivers so small or so saline, that it would be impossible again to locate towns of equal size in the same places, unless a far better system of irrigation were introduced. There is not the slightest trace of such a system, although if it had existed, its canals would surely have been more durable than those built under the present crude system. Moreover, in three places, Vash Sheri, Miran, and Ying-pen, almost the entire irrigation system of old times is preserved, including both dams and canals; and it is evident that the ancient methods of utilizing water were precisely like those of to-day. The abandonment of the ruined towns cannot have been due to the encroachment of sand, for in some places, such as Miran, Vash Sheri and Ying-pen, there is no sand; in others, such as Endereh, the amount is small; and even in places such as Dandan-Uilik, where there is much sand, it appears to have encroached upon the inhabited area after, not before, the vegetation had begun to die for lack of water. It is possible that in one or two minor cases the diminution of the water supply may have been due to the diversion of part of the headwaters of a stream, but in most cases this is impossible. Manifestly, such diversion in one place would cause a larger stream and more abundant vegetation elsewhere; but as a matter of fact, the amount of vegetation has diminished everywhere. Neither the theory of the diversion of tributaries, that of the encroachment of sand, that of the former existence of a better irrigation system, nor that of the destruction of forests offers any explanation of the fact that many streams have grown much more saline. This can be accounted for only on the theory of a change of climate, a theory which not only is in harmony with all the known geographic facts, but which also explains many of the events of history.

We have seen that in the Lop basin, as in Kashmir, desiccation has not been a steady process. Fluctuations or pulsations have been the rule, some large and long, some slight and short. From the third to the sixth century of our era, there seems to have been a time of intense aridity succeeding a period of relatively abundant moisture, during which the rivers and hence the population were much larger than at present. During the time of aridity, many old towns were abandoned, including Rawak, the major part, if not all, of Dandan-Uilik, Karadong, the Niya River town, Tuholo, Lulan, and possibly others whose dates are as yet unknown. At the same time, the great trade route through Lulan was given up in favor of a longer one. At a later date, roughly between the ninth and the sixteenth centuries, there appears to have been an epoch of somewhat more favorable climatic conditions. Choka was built on the Karatash River; Kenan and Lachinata, as well as Chira and Gulakhma, flourished lower down on the main stream; a road existed across the desert north of the present end of the Keriya River: Bilel Konghan grew up to succeed Tuholo; and Yingpen, which appears to have been abandoned by its Buddhist builders, was reoccupied by Mohammedans. During the last few centuries, as the vegetation shows, there has been again a tendency toward aridity.

The inferred history of Lop-Nor during the last two thousand years may now be summed up. We have first a comparatively large lake. It is said to have had a length of seventy-five miles each way, and this was in spite of the large amount of water which must have been diverted from the Tarim River by the populous towns of Lulan and of more remote districts. Next, during the early centuries of the Christian era, there is a decrease in the recorded size of the lake, and this even though the towns of Lulan and other places were being abandoned and their water supply set free to reinforce the lake. Then, in the Middle Ages, there appears to have been an expansion of the lake. This can hardly have been due to diminished use of the rivers for irrigation, for at that time the population of the Lop basin appears to have been greater than now, though not equal to that of the Buddhist epoch of prosperity about a thousand years earlier. Finally, during the last few hundred years, there has been a decrease both in the size of the lake and in the population about it. Thus the fluctuations of Lop-Nor agree perfectly with the climatic pulsations of which we have found proof in other parts of the Lop basin and in Kashmir. Far to the west, at Ordam Pasha, Stein describes ruins for which no adequate water supply now exists. And far to the east, the united Bulundsir and Tan-Ho rivers appear once to have flowed to Lop-Nor. On the dry lower part of the course which they formerly followed, the natives describe two ruined sites of the type with which we are familiar. The Chinese of Dung Khan (Tung Hwang, or Sa-Chow), higher up on the Tan-Ho, say that the ruins were abandoned by their ancestors long ago because the water of the rivers would no longer reach them. In the same region, the old Chinese local history, translated by Mr. Hunter, says that certain mountains were formerly covered with snow all the year round, though now they are free from it during the summer. Everywhere in the Lop basin tales of sand-buried cities still to be discovered haunt the desert. Throughout the entire fifteen hundred miles of longitude and four hundred of latitude of the Lop basin, the same great series of climatic pulsations appears to have occurred.

The Caspian Sea and Its Neighbors

The extent and possible significance of these changes will be manifest from a brief résumé of the main conclusions to which we have thus far been led. Including Gyoljuk, our survey of western and central Asia has dealt with six distinct basins. On the west lies Gyoljuk in Turkey; then come the Caspian basin in Russia, and that of Seyistan to the south in Persia; while far to the east we have Lop and Turfan in the heart of Asia forming part of China, and Kashmir south of the Himalayas in India. If we omit the Volga and the European portions of the Caspian drainage area, the limits of our six basins lie over sixteen hundred miles apart from north to south, and over three thousand from east to west. All this vast area seems to have been subject to the same great waves of climatic change.

In the ancient days when the Oxus River entered the Scythian gulf of the expanded Caspian Sea, and Lake Gyoljuk discharged permanently to the Tigris, the lake of Seyistan had not yet been converted into dry land by the giants; Kashmir was so cold and snowy that agriculture was impossible; its people were nomads, who were obliged to drive their flocks southward in winter to the warm plains of India. In the Lop basin an opposite state of affairs prevailed, and conditions were highly favorable. The rivers were full of water; Lop-Nor was the "Great Salt Lake"; the desert was comparatively small and the zone of vegetation extensive; and on all sides there was a density of population and a degree of prosperity far beyond those of to-day. And in the Turfan basin the same was probably true.

A great change took place throughout the six basins during the early centuries of the Christian era. The lakes of Gyoljuk, Seyistan, the Caspian, Lop-Nor, and presumably Turfan were greatly reduced in size. In the case of the first three, parts of the old lake-beds were utilized as sites for villages. Except in Kashmir, the change of climate appears to have brought disaster, although in Turkey the question has not yet been investigated. In the other regions, scores of once prosperous oases were abandoned for lack of water. A few of the displaced inhabitants probably went into the mountains and dug canals such as those of Son Kul. Others perhaps went to Kashmir, which now became warm enough for agriculture, and hence able to support a far larger population. The rest appear to have been impelled to start hither and thither in waves of migration to confound the civilized world.

Again there came a change. The process of desiccation gave place to a slight, but important tendency toward increased rainfall and lower temperature. Kashmir became colder and more snowy, and hence more isolated; the rivers of Lop and Turfan gained greater volume; and the lakes of Lop, the Caspian, and Seyistan expanded once more. The habitability of the arid regions began to increase; migrations came to an end; and Central Asia was prosperous for a time. Finally, a latest and slightest change took place in the other direction; and we seem to-day to be in the midst of an epoch of comparative equilibrium, with no marked tendency toward climatic change in either direction.

Weathering and Soils

The area of rock exposed to the atmosphere at the surface of the globe is a vast laboratory where physical forces are at work and chemical reactions take place that ultimately reduce the solid rock to loose débris, fragments of its former self usually with a different composition. These forces act inward from without and so do not penetrate deeply, but the agents of erosion remove the newly formed material and expose fresh surfaces to the destroying atmosphere. Thus the work is carried on and even mountain ranges fall to pieces and eventually disappear.

This continual destruction is easily understood if we realize that the minerals in the rocks are chemical compounds and, as such, can exist only in an environment essentially similar to that in which they were formed. Changing conditions inevitably bring about destruction, more rapid in some cases than in others, but ultimately the same for all. These changing conditions and the resulting instability are the subject of the following paragraphs (Merrill, 1904, pp. 172-173):

> The stability of chemical compounds is governed by prevailing conditions. A form of combination stable under conditions existing to-day may, under those of to-morrow, become impossible . . . the conditions under which the more superficial portions of the earth's crust exist are ever changing, and as a result old compounds are broken up and new continually formed. All over the earth rocks laid down as sediments on oceanic floors have been folded, faulted, and pushed out of

place until brought under influences as different from those under which they were formed as is possible to conceive. Molten magmas cooling suddenly on the immediate surface formed compounds in which mere loss of heat was the controlling factor, but which time proves to be unstable. Slow cooling, deep-seated magmas have been, and are being, continually exposed by denudation, and thus brought under new influences and environments. Hence a constant readjustment is everywhere going on, which, as we shall see, is manifold in its physical manifestations. As where an entire building is razed to the ground, and another of quite different architectural features constructed from the old materials; or again, where, without change of general plan, old timbers are here and there replaced by new, so here we have at work a series of processes in part seemingly destructive and in part constructive, but all tending towards one end.

The firm and everlasting hills we must learn to regard as neither firm nor everlasting. Whole mountain chains of the geological yesterday have disappeared from view, and as with the ancient cities of the East, we read their histories only in their ruins. Yet, in all this seemingly destructive process of breaking down, decomposition, and erosion, there is traceable the one underlying principle of transformation from the unstable to that which is to-day more stable. Nothing is lost or wasted: It is a change which began with the beginning of matter; which will end only with the blotting out of matter itself. There are no traces of a beginning, there is no prospect of an end.

The effect of climate upon geological processes, pointed out earlier, is nowhere more marked than in its relation to weathering. Rocks at the surface are subject to destruction wherever they are exposed; but actual decay of mineral matter into a base for productive soil is negligible in arid regions, whereas moisture and warmth promote decomposition. Some notable examples of disintegration due to temperature changes are given below (Merrill, 1904, pp. 182-183):

> . . . H. Von Streeruwitz states that the rocks of the Trans Pecos (Texas) undergo a very rapid disintegration from diurnal temperature variations, which here amount to from 60°-75° F. He says: "I frequently observed in summer, as well as in winter time, on the heights of the Quitman Mountains a peculiar crackling noise and occasionally loud reports, . . . and careful research revealed the fact that the crackling was caused by the gradual disintegration and separation of scales from the surface of the rock, and the loud reports by crackling and splitting of huge boulders."

Merrill (1904, p. 183) has himself observed the effect of disintegration in the desert of lower California:

> . . . Throughout the desert regions of lower California, as observed by the writer, the granitic and basic eruptive rocks subject to very little rainfall, and hence almost completely bare of vegetation, under the blistering heat of the desert sun have weathered down into dome-shaped masses, their débris in the form of angular bits of gravel being strewn over the plain. . . . Aside from a whitening of the feldspathic constituent, due to the reflection of the light from its parted cleavage planes, scarcely any change has taken place, and indeed it more resembles the finely comminuted material from a rock-crusher than a product of natural agencies.

The following contrasts the results of weathering in a different climate (Merrill, 1904, p. 283):

> . . . In a warm, moist climate chemical decomposition may or may not keep pace with disintegration, according to local conditions, so that the resultant material may be in the form of an arkose sand, as in the District of Columbia, or a residual clay, as in the more superficial portions of the residual deposits to the southward. In certain cases, or among certain classes of rocks, the decomposition proceeds at so rapid a rate that there is scarcely any apparent preliminary disintegration. Local circumstances and character of rock masses being the

same, we are, however, apparently safe in assuming that in warm and moist climates decomposition follows so closely upon disintegration as to form the more conspicuous feature of the phenomenon, while in dry regions, or those subject to energetic frost action, mechanical processes prevail and disintegration exceeds decomposition.

It is evident from this quotation that climate is not the only factor involved. Local conditions of exposure and the kind and character of the rock of course modify the result, but in a broad way the climatic control is the important one. The following quotations from Russell (1889, pp. 12-13, 15-17, 26-27) contrast the deep decay of rocks in the southern Appalachians with the slight effect in the more arid West:

Subaërial Decay of Rocks

The formation of soils by the decomposition of rocks in place has already received a large share of attention, but recent observations suggest that changes of this nature have a wider geological bearing than has generally been assigned them, and that questions relating to the origin and distribution of soils and subsoils may still be discussed with profit.

Decay of the Crystalline Rocks of the Piedmont Region

In traveling south from the southern margin of the moraines left by the Pleistocene ice sheet of northeastern America, along the belt of crystalline rocks bordering the Appalachian Mountains on the east, the surface exposures exhibit greater and greater evidences of decay as one proceeds.[1] In Pennsylvania and Maryland the mica schists and allied rocks are frequently disintegrated to a depth of many feet, so that they may be removed with a pick and shovel. The strata, however, are for the most part simply broken down, so far as is apparent to the eye, although chemical alteration, especially of the feldspars, has unquestionably occurred. With the exception of a few feet at the surface, however, it is principally disintegration, not decomposition, that has taken place. In a handful of fragments the eye immediately determines the character of the rock from which they were derived; if chemical change was far advanced this would not be the case. It is difficult to ascertain the depth of this alteration, but in general it may be taken at from fifteen to thirty feet; localities are not uncommon, however, where well-marked disintegration has reached a depth of fully 50 feet below the surface. Typical examples of residual clay—the extreme result of subaërial decay—are not common in this portion of the Appalachian belt, but may occasionally be seen in railroad cuts and similar excavations.

---

[1] The observations on the decay of rocks presented in this paper refer principally to changes that are obvious to the eye, and not to the alterations frequently detected when thin sections of apparently sound rocks are examined with a microscope.

As one travels south from the Potomac a great increase is seen in the extent and in the depth of the chemical changes that have affected the outcrops. Throughout nearly the entire area underlaid by crystalline rocks in Virginia and the Carolinas east of the Blue Ridge the soil is red clay, which is a residual deposit produced by the subaërial alteration of the rocks on which it rests. Over large areas this alteration reaches more than a hundred feet below the surface, but, owing to lack of exposures, its full extent is seldom seen.

The depth at which decayed rocks have been observed assures us that the downward limit of the changes produced in rocks by atmospheric agencies is not always determined by the level of stream erosion, or even by the horizon of the ocean surface. This may perhaps be due to recent subsidence, which has depressed the decayed rock below the level at which the alteration took place, for it is evident that the changes due to atmospheric influences are of a different character from those produced by the circulation of water through rocks at great depth, although there is no sharp line of demarkation between the two processes.

In cuts along the line of the Carolina Central Railroad east of Wadesborough, on the Cape Fear and Yadkin Valley Railroad near Jonesborough, and along the North Carolina Railroad west of Raleigh, N. C., fine sections of decomposed crystalline rocks are exposed. These are but isolated examples, however, of what can be seen over thousands of square miles in the great area of crystalline rocks in which they are situated. At the localities cited above the rocks retain little of their original character, but are now variously colored clays, which, when moist, can be molded in the fingers or cut with a pocket-knife. In many places the layers of granite, mica schist, hornblende schist, talcose schist, and similar rocks have been twisted and folded so that in their present eroded condition the bedding in the outcrops is nearly perpendicular. In such instances, when the rock is excavated, as in railroad cuts . . . the entire mass, to a depth exceeding fifty feet, is a soft, plastic clay, which reveals its original stratification and lamination by an almost infinite number of vertical bands and lines of various tints and shades. Bright red and brilliant yellow predominate, but these harlequin tints are many times blended with gray, purple, and white in such a way as to produce most remarkable examples of natural coloring.

Decay of the Rocks of the Newark System

In the rocks of the Newark [Triassic] system in Virginia and North Carolina a widespread decomposition, similar to that affecting the older rocks of the same region, was observed at many localities.

The brecciated conglomerate which is found wherever the bottom of the Newark system is exposed is composed of both rolled and angular fragments of the adjacent crystalline rocks. These were compact and solid when deposited as pebbles and bowlders, but they are now often as thoroughly disintegrated and decomposed as the neighboring rocks described above. In a cut on the line of the North Carolina Railroad, 10 miles west of Wadesborough, there is a fine exposure of the basal conglomerate of the Newark. The north side of the excavation still stands as a perpendicular wall about twenty feet high, in which the variously shaped fragments composing the brecciated conglomerate are clearly distinguishable. At a little distance the rock appears almost identical with the Potomac marble, with which it agrees in geological position. On examining more closely, however, one is surprised to find that it is completely decomposed, and that, when moist, it can be cut with a pocket-knife, through pebbles and matrix alike, as easily as so much potter's clay. The full depth of the alteration in this instance is not revealed, but it extends more than thirty feet below the surface without change in character. Most of the pebbles observed were formed of talcose schist and the cementing material was apparently derived from rocks of the same composition.

In the ordinary brown sandstones and sandy shales of the Newark system throughout Virginia and North Carolina but little subaërial decay is apparent to the unassisted eye, except in the grains of feldspar which they contain. Some of the strata in this formation are composed of plastic red clay, but whether this was deposited in its present condition or is the product of subsequent decay it is not always possible to decide.

The most remarkable example which I observed of the change that rocks undergo when long exposed to the atmosphere occurs in the trap dikes traversing the Newark system of North Carolina. These are composed of dolerite of the same character as the "traps" so abundant in New Jersey and in the Connecticut Valley, and are exceedingly numerous throughout the various Newark areas south of the Potomac. In a single section, 13 miles in length, of the Newark area which crosses Anson County, N. C., over fifty trap dikes were observed, varying from a fraction of a foot to seventy-five feet in width. It is probable that many others exist which escaped notice.

These dikes trend approximately north and south and are nearly vertical in dip. They are usually undistinguishable in the topographic relief of the region, but their presence is occasionally indicated on the surface by long lines of weathered trap bowlders. Sections of the dikes may frequently be observed in railroad cuts, and in such instances it is found that decomposition has reached to a great depth. In fresh sections forty or fifty feet deep the decomposition extends to the bottom of the exposures, without any indication of approaching its lower limit. Many dikes are completely decomposed throughout, and the originally hard, tough, bluish dolerite, which would ring under the hammer, has been transformed into a yellowish, clay like mass that can be molded in the fingers and cut like putty. In some cases, especially in the larger dikes, the decomposition is only partial, and the loose rotten mass contains rounded bowlders in process of disintegration, in the center of which the rock still exhibits its original characteristics. These bowlders usually occupy the center of a dike, as seen in vertical section, but at times there are two or more vertical bands of them distributed through the decomposing rock. The sides of the fissures through which the trap ascended are hardened or metamorphosed at some localities by the contact of the igneous rock, and thus rendered unusually durable. In such instances the trap is often completely decomposed, while the walls of hardened sandstone exhibit no sign of disintegration.

Absence of Decayed Rocks in the Far West

Nothing comparable with the extensive disintegration and decay of the rocks forming the southern portion of the Appalachian Mountains has been observed by me during somewhat extended journeys through other portions of the United States. In the Northeastern States the records of such decay are mostly obscured and obliterated by glacial deposits. West of the Mississippi, in New Mexico, Colorado, Idaho, Utah, Nevada, Oregon, and California, only secondary glaciers originating from local centers existed during the glacial epoch. The rocks in large portions of this region have presumably been subjected to subaërial influences fully as long as in the South Atlantic States, but no marked evidences of general decay are to be seen. In the mountains of the Far West, which, as nearly as I can judge, may be fairly compared with the more elevated portions of the southern Appalachians, so far as the conditions of transportation are concerned, the evidences of subaerial decay are not strongly pronounced, and, in fact, are usually absent. It is a matter of observation that the soil formed by the decay of a great variety of rocks is a red clay, which, in the more advanced stages of decomposition, is strikingly similar, both in appearance and in constituents, the world over. In the arid portion of the Far West soils of this character are wanting, and the prevailing tone of the landscape, so far as it is influenced by the color of the soil, or by the color of subaerial deposits generally, is subdued and unobtrusive, being usually gray, or light yellow brown. The brilliant coloring on the mountains and the gorgeous hues revealed in the cañons of this region are not due to products of decay, but to the inherent tints of the rocks. The marked contrast that exists in the colors of the superficial deposits in the South Atlantic and South Pacific borders of the United States can be illustrated in fancy by comparing the ashen tints of the Mojave desert with the brilliant reds and yellows that would be revealed could the vegetation be removed from Virginia and her sister States.

In considering the absence of red soils in the Far West the arid region alone is referred to. There are areas of considerable extent on the west slopes of the Sierra Nevada where deep rock decay has taken place and where the red color of the soil reminds one of the southern Appalachians. In this region the present rain-fall is about forty-five inches, annually, and the country is clothed with vegetation. The climatic conditions thus approximate to those prevailing in the Middle Atlantic States, and the decay observed in the rocks, including schists, slates, and limestones, is what one would expect from the climatic environment. The west slope of the Sierra Nevada in central California is a place inclined at a gentle angle, in which the streams have sunken their channels a thousand feet or more. The cañons are narrow, with precipitous sides, and are floored with rock that has suffered but little decay. These conditions indicate that the region referred to underwent a long period of disintegration before the plain was tilted so as to allow the streams to excavate their present channels. That the stream channels are of more recent origin than the principal part of the rock decay is shown by the occurrence of residual clays, sometimes fifty or seventy-five feet thick, on the hill-tops. These conditions are well illustrated in the hydraulic mines on Feather River, and may be studied to advantage at Colfax, Cal.

There are probably other areas in the Far West where rock decay is as marked as on the west slope of the Sierra Nevada, but they have not come under my notice. What the effects of the heavy rain-fall, and consequently dense forests, of the northern part of the Pacific Slope may be on the decay of rocks remains to be observed.

The summary of the results of this investigation, given below (Russell, 1889, pp. 31-32), emphasizes the importance of the climatic control over weathering, the processes that prepare the way for the other agents of denudation:

> On considering the geographical distribution of residual deposits, together with other facts bearing on the question, it seems safe to conclude that, in general, subaërial decay is more rapid in warm than in cold regions, and is far greater in humid than in arid climates. The most favorable conditions occur in warm, moist climates.
>
> The intimate relation between climatic conditions and rock decay here stated might perhaps be considered as simply a coincidence, and not of the nature of cause and effect. The writer is not prepared to discuss in all their details the chemical processes which have transformed the superficial portions of the earth's crust and rendered it suitable for the formation of soil and the growth of vegetation, but the effects of climate in this connection may be designated in a general way.
>
> Among the first conditions influencing rock decay is temperature. Its direct effects are felt in two ways: (1) The warm

waters of temperate and tropical climates have greater solvent power than the colder waters of higher latitudes; (2) In warm regions the surface waters are enabled to exert their influences throughout the year, whereas in colder climates the ground is frozen during a portion of the year at least, the percolating of surface water is checked, and its chemical effects are decreased. More than this, precipitation is, in general, greater in low than in high latitudes, and takes the form of warm rain which saturates the ground instead of falling in great part as snow. Genial temperatures and abundant rain-fall are accompanied by luxuriant vegetation, which not only retains rain-water at the surface and allows it to percolate slowly downward, but imparts to it various organic acids, thus increasing its solvent power. The tendency of all these conditions is to produce greater chemical alterations in the rocks of warm, moist regions than in those of cold countries. As the regions of abundant rain-fall and rank vegetation pass by insensible gradations into cold or arid, barren regions, so the products of rock decay change by insensible gradations from regions like the southern Appalachians, where they reach a maximum, to other areas where they are for the most part wanting.

The formation of soil is only an incident in the denudation of the land; it may be swept away as quickly as it is formed and leave the rock barren and unproductive. Usually, however, some of it remains in place or is merely moved to lower land and then it is of fundamental importance to life. In a sense soil is the connecting link between inorganic matter and the living world because plants draw sustenance from it and they in turn supply food for animals. Directly or indirectly then, all life depends upon the mineral matter prepared by nature so that it can be transformed by plants into organic matter.

We are apt to consider the soil as commonplace "dirt," unworthy of study. The ancient Greeks, however, were more enlightened; they recognized their dependence upon the soil and in their mythology the goddess Gaea personified the powers of production in the ground.

Scientific study has explained part of this mystery, but has also added immensely to the interest of the soil. Now we realize that the veneer of "dirt" covering the solid rock is a priceless heritage of long ages, built up by complex processes which are even yet but partly understood.

Milton Whitney (1925, pp. 26-33) as chief of the Bureau of Soils in the U. S. Department of Agriculture, made a lifelong study of the soil and represents it as a living thing with a complex organization:

> The higher animals have a skeleton to support the various membranes and organs that take part in the functional activities. . . .
>
> The soil has a corresponding skeleton of small rock fragments between the supporting walls of which the functional activities perform. This skeleton of the soil differs as does the skeleton of animals in a great variety of forms adapted to the different functional activities that nature has provided for the wonderful variety of natural plant associations and for human needs. Some soils are composed largely of coarse gravel or bowlders, others have a large proportion of coarse or of medium sand while others are composed largely of fine-grained silts and clays. These soils of different texture differ in their functional activities and relation to crop adaptation and production. There may be one texture in the soil, another in the subsoil and still another in the substratum. There may be beds of gravel or of hardpan below the surface, which affect the functional activities of the soil and what it can do in the way of raising crops and the way it must be treated to insure satisfactory results. A coarse-grained, loose, incoherent sand is no more adapted to, and no more efficient in producing a crop of wheat than is a dog adapted to perform the work of a horse on the farm. Both the dog and the horse may be essential in their way on the farm but they are not useful in the same way nor are they interchangeable. So the coarse sandy soil may be made of use but the purposes for which it can be efficiently used are as different from those of the well-drained clay soil as the purpose for which the dog is used on the farm differs from the purpose for which the horse or cow is used. The

texture of the soil material therefore has an important place in the classification of soils for human needs.

The animal has certain tendons and muscles to hold the bones in place and take part in the functional activity of the body. The soil colloids act in a similar manner to hold the fragments of rocks together and give plasticity in the wet soil and compactness or hardness in the dry soil. Methods have only recently been devised for separating this colloidal material from the skeleton of the soil which permits a study to be made of the composition, constitution, and physical properties of the material. . . .

The stomach and other organs of the animal have a colloidal lining to absorb and regulate the supply of nutrient materials in various parts of the body. The soil colloids act in the same way in absorbing and regulating the food supply in the soil. Were it not for these colloids in the soil which have the power of withdrawing from active solution mineral and organic substances as well as gases, all soluble material would be readily washed out of the soil by rainfall instead of being held in proportion to the needs of crops as is at present done. . . .

The animal has a complicated digestive system to prepare food that is eaten for assimilation by the body and for final elimination of unused food material and of waste matter from the body itself. The soil has a similar digestive system to prepare food for assimilation by plants and for the elimination of waste material in the soil and of waste material thrown into the soil by the plant itself. The soil is the home and the ultimate source of the bacteria, enzymes and oxidation processes that make for health or disease in the animal body. The food of the soil, that is the food that keeps alive the digestive agents in the soil, is first the crop and its waste products and secondly the organic remains of plants and animals. An animal has to be constantly fed with organic matter with the attendant mineral matter contained therein to maintain its digestive functions and an adequate food supply for growth and energy.

The animal has a respiratory system to assist digestion and the elimination of waste products. This takes place mainly through the lungs but also through the skin and consists in taking in a fresh supply of oxygen or air to assist in the oxidation process of the body and the elimination of the unused portion of the air together with gaseous products formed through oxidation from the body.

The soil has a similar system which is called aeration. The soil breathes deeply and frequently to depths of fifty feet and probably to much greater depths. This interchange of fresh air with the soil likewise brings about oxidation and assists in digestion and accomplishes the direct elimination of the gaseous products of digestion from the soil. We know that drainage conditions have much to do with the extent of this aeration and we commonly use the method of cultivation to assist the digestive processes in the soil.

The animal has a circulatory system in the blood to distribute the nutrient material and waste products to different parts of the body where they can be used by the growing parts or eliminated from the system.

The soil has a similar circulatory system in the movement of soil moisture which distributes nutrient material and waste products. It has the larger channels through which water passes rather quickly as in the veins of the animal and it has the capillaries where the movement is slower but more effective in many details. While we have been used to studying capillary action in tubes of a few feet in length and while lysimeter measurements have been made of a few inches or a foot or two of a soil . . . there are evidences that this circulatory system of a soil is very much more extensive than we have heretofore conceived and that these capillaries act for many miles in depth and in lateral extent, so that the soil we cultivate represents but a thin skin on the earth which contributes as a whole to the circulatory system and all that this means in the distribution of nutrient material to the soil layer.

We cannot fail to see in this broad and comprehensive view that the soil is truly a living thing, that it has very complicated functional activities that react on one another and affect its productive power in the growth of plants. It is certainly not inert material. It will be seen also that a man having a sympathetic, an intuitive, or an inherited ability to handle the soil as he would have to handle a particular breed of cow, has a great advantage in the struggle for existence and in competition with a man who is lacking in knowledge and experience of the particular type of soil upon which he happens to be located. It also shows very clearly the complexities of the problem presented to the soil scientist in understanding the soil and its properties as related to the production of crops. It also indicates very clearly that the last word in crop production cannot even be speculated on until we have a clearer knowledge of the soil as a living thing.

BIBLIOGRAPHY

Chapter II—Climate; Weathering and Soils

Isaiah Bowman, *Desert Trails of Atacama.* American Geographical Society, Special Publication No. 5, 1924, pp. 40-41, 62-63.

C. E. P. Brooks, *The Evolution of Climate.* New York: R. V. Coleman, National Book Buyers' Service, 1922, pp. 149-153.

Ellsworth Huntington, *The Pulse of Asia.* Boston and New York: Houghton Mifflin Co., 1907, pp. 6-9, 277-279, 280-283, 292-294, 356-358.

George P. Merrill, *A Treatise on Rocks, Rock-weathering and Soils.* New York: The Macmillan Company, 1904, pp. 172-173, 182-183, 283.

Albrecht Penck, *Climatic Features in the Land Surface.* American Journal of Science, vol. 19, 1905, pp. 165-172.

I. C. Russell, *Subaërial Decay of Rocks and Origin of the Red Color of Certain Formations.* U. S. Geological Survey, Bulletin 52, 1889, pp. 12-13, 15-17, 26-27, 31-32.

Milton Whitney, *Soil and Civilization.* New York: D. Van Nostrand Company, 1925, pp. 26-33.

CHAPTER III

STREAMS AND VALLEYS

Early Ideas Concerning Streams

> All the most fertile parts of the globe were formed by alluvial depositions: alluvial agency appears to have been the means employed, in the economy of nature, to prepare the world for the residence of social and civilized man. The most ancient cities of which we have any authentic record, Babylon, Ninevah, and Thebes, were founded in the midst of alluvial soils, deposited by the Euphrates, the Tigris, and the Nile: indeed, it does not appear unreasonable to believe that the formation of soils for the support of vegetables and animals is the final end to which all terrestrial changes ultimately refer.

This somewhat naïve statement (Bakewell, 1839, p. 387) expresses a realization of one of the greatest benefits rendered by streams to man. The economic effects of streams and valleys were understood long before any accurate idea was gained as to the place of running water in the philosophy of Earth processes. Among many people even to-day the belief is common that large stream valleys were formed by great and sudden catastrophes in former ages. Not a few inhabitants of Arizona explain the Grand Canyon as a great fissure or rupture in the Earth's crust. It is inconceivable to them that the comparatively small Colorado River could have cut this gigantic chasm out of solid rock.

Origin of Valleys

More than a century ago, when modern ideas in Geology were only beginning to take form, many scientific men steadfastly believed that valleys were the result of violent cataclysms that had taken place during dark and stormy periods of unrest in the history of the Earth. James Hutton (1726-1797) of Edinburgh, to whose masterly reasoning the science of Geology owes much of its development, was one of the first to prove that valleys are the result of the slow but inevitable work of water running off over the land. Reasoning from this fact, Hutton argued that the processes now at work on the Earth have always been at work, and that no event more startling nor more catastrophic than the events observable to-day, has ever affected the globe. Our modern geologic beliefs center around essentially this idea. The following statement of Hutton's view, written by his friend and exponent John Playfair (Playfair, 1802, p. 102), has become famous:

> Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportioned to its size, and all of them together forming a system of valleys, communicating with one another, and having such a nice adjustment of their declivities, that none of them join the principal valley, either on too high or too low a level, a circumstance which would be infinitely improbable if each of these valleys were not the work of the stream that flows in it.
>
> If, indeed, a river consisted of a single stream without branches, running in a straight valley, it might be supposed that some great concussion, or some powerful torrent, had opened at once the channel by which its waters are conducted to the ocean; but, when the usual form of a river is considered, the trunk divided into many branches, which rise at a great distance from one another, and these again subdivided into an infinity of smaller ramifications, it becomes strongly impressed upon the mind that all these channels have been cut by the waters themselves; that they have been slowly dug out by the washing and erosion of the land; and that it is by the repeated touches of the same instrument that this curious assemblage of lines has been engraved so deeply on the surface of the globe.

In another place the same author (Playfair, 1802, pp. 116, 124, 354) says:

> . . . A river, of which the course is both serpentine and deeply excavated in the rock, is among the phenomena by which the slow waste of the land, and also the cause of that waste, are most directly pointed out. . . .
>
> The structure of the valleys among mountains, shows clearly to what cause their existence is to be ascribed. Here we have first a large valley, communicating directly with the plain, and winding between high ridges of mountains, while the river in the bottom of it descends over a surface, remarkable, in such a scene, for its uniform declivity. Into this, open a multitude of transverse or secondary valleys intersecting the ridges on either side of the former, each bringing a contribution to the main stream, proportioned to its magnitude; and, except where a cataract now and then intervenes, all having that nice adjustment in their levels, which is the more wonderful, the greater the irregularity of the surface. These secondary valleys have others of a smaller size opening into them; and, among mountains of the first order, where all is laid out on the greatest scale, these ramifications are continued to a fourth and even a fifth, each diminishing in size as it increases in elevation, and as its supply of water is less. Through them all, this law is in general observed, that where a higher valley joins a lower one, of the two angles which it makes with the latter, that which is obtuse is always on the descending side; . . . what else but the water itself, working its way through obstacles of unequal resistance, could have opened or kept up a communication between the inequalities of an irregular and alpine surface . . .
>
> . . . The probability of such a constitution (arrangement of valleys) having arisen from another cause, is, to the probability of its having arisen from the running water, in such a proportion as unity bears to a number infinitely great.

Hutton's conclusions aroused strong opposition in many scientific men of the time; there ensued a long and heated debate, which was still in progress as late as 1878, although by that time all sound and rational thinkers had seen that the "Huttonian theory" was founded on unshakable logic. A typical counter-argument (Buckland, 1824, pp. 150, 317), published in America in 1824, reads as follows:

> . . . The general belief is, that existing streams, avalanches and lakes, bursting their barriers, are sufficient to account for all their phenomena, and not a few geologists, especially those of the Huttonian school, at whose head is Professor Playfair, have till recently been of this opinion. . . . But it is now very clear to almost every man, who impartially examines the facts in regard to existing valleys, that the causes now in action, mentioned above, are altogether inadequate to their production; nay, that such a supposition would involve a physical impossibility. We do not believe that one-thousandth part of our present valleys were excavated by the power of existing streams. . . . In very many cases of large rivers, it is found, that so far from having formed their own beds, they are actually in a gradual manner filling them up.
>
> Again; how happens it that the source of a river is frequently below the head of a valley, if the river excavated that valley?
>
> The most powerful argument, however, in our opinion, against the supposition we are combating, is the phenomena of transverse and longitudinal valleys; both of which could not possibly have been formed by existing streams.

Many scientists of the nineteenth century, while recognizing that stream valleys were carved by stream erosion, persisted in attributing them to providential design. Edward Hitchcock (1861, p. 221), a Vermonter, discourses thus upon the valleys of his state:

> Nor has this great work been without design; but, like all other works of the creator, we can see definite objects accomplished by it. And when we see a railroad following a valley of erosion from the mouth of White River to Burlington, across

the whole central part of the State, and passing by its metropolis, do we not see one of those objects? For without such erosions, such communications would hardly have been possible. And though the construction of a railroad, even through such a valley, be a great labor, yet just think how vastly greater has been the previous work performed by Nature, and man's part sinks into comparative insignificance.

The same reasoning as to providential design applies to other railroad routes in the State; and also some valleys equally well adapted for steam communication. And if it be said that these last cases show that there has been no special design in their erosion, we reply that railroads are not the only means of intercommunication facilitated by them; but we ask the objector to wait a hundred years to see how many more of these valleys will echo the steam whistle before that time—for some of us well remember the day, and that too since we began to look at its geology, when it had not been sounded within the limits of Vermont.

To Hitchcock, curiously enough, the cutting of railroad tunnels did not apparently seem sacrilegious.

Analysis of Erosion

The publication of Hutton's ideas was followed throughout the nineteenth century by careful observations of the behavior of streams and erosion of their valleys. The most important were made in America in the period following the Civil War, by the Government parties that were sent to survey the public lands of the new West. One striking conclusion was reached by a New York boy, G. K. Gilbert, who joined one of these parties, and who through the excellence of his work became Chief Geologist of the U. S. Geological Survey, and one of the foremost scientists of his time. In a report on the stream valleys of a part of Utah (Gilbert, 1880, pp. 117-118), he wrote:

Every slope is a member of a series, receiving the water and the waste of the slope above it, and discharging its own water and waste upon the slope below. If one member of the series is eroded with exceptional rapidity, two things immediately result: first, the member above has its level of discharge lowered, and its rate of erosion is thereby increased; and second, the member below, being clogged by an exceptional load of detritus, has its rate of erosion diminished. The acceleration above and the retardation below, diminish the declivity of the member in which the disturbance originated; and as the declivity is reduced the rate of erosion is likewise reduced. But the effect does not stop here. The disturbance which has been transferred from one member of the series to the two which adjoin it, is by them transmitted to others, and does not cease until it has reached the confines of the drainage basin. For in each basin all lines of drainage unite in a main line, and a disturbance upon any line is communicated through it to the main line and thence to every tributary. And as any member of the system may influence all the others, so each member is influenced by every other. There is an interdependence throughout the system.

While Gilbert was studying in the West, another keen observer and logical thinker was developing in the person of J. W. Powell, a major of engineers, who was working for the Government in Colorado and Utah. His report written on his return to Washington, contained among other things these striking statements: *Mountains cannot long remain mountains; they are ephemeral topographic forms. Geologically all existing mountains are recent; the ancient mountains are gone.* Powell clearly stated a far-reaching truth; the higher a block of the Earth's crust is heaved up to form a mountain range, the more rapidly do the streams cut valleys in it and wear it down. This conception is confirmed from every continent of the Earth; all the highest mountains, such as the Alps, the Rockies, and the Himalayas, are of recent origin; the mountains that were formed in the earlier periods, such as the Appalachians and the Scottish Highlands, are worn low.

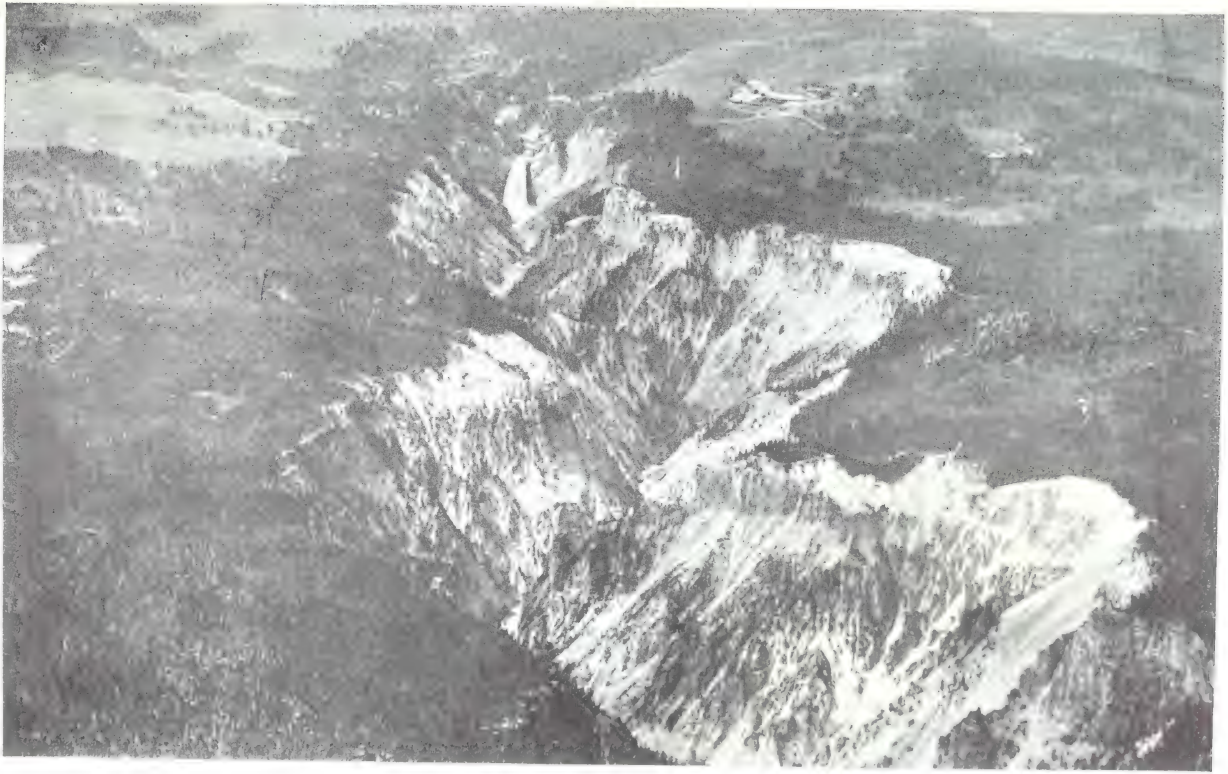
It was partly as a result of the work of Gilbert and Powell and another engineer named C. E. Dutton that Professor W. M. Davis of Harvard was enabled to draw a continuous picture of a land area being slowly eaten into by streams, worn away, and reduced to a lowland. This picture, which we call the "cycle of stream erosion," has become the fundamental basis of the study and interpretation of land forms, and as such is familiar to every student of geology. A statement of the cycle in Davis's own words, extracted from his essay on the land forms of Pennsylvania (Davis, 1889, p. 200) is here appended:

The Complete Cycle of River Life: Youth, Adolescence, Maturity, and Old Age. The general outline of an ideal river's history may now be considered, preparatory to examining the special history of the rivers of Pennsylvania as controlled by the geological events just narrated.

Rivers are so long-lived and survive with more or less modification so many changes in the attitude and even in the structure of the land, that the best way of entering on their discussion seems to be to examine the development of an ideal river of simple history, and from the general features thus discovered, it may then be possible to unravel the complex sequence of events that lead to the present condition of actual rivers of complicated history.

A river that is established on a new land may be called an original river. It must at first be of the kind known as a consequent river, for it has no ancestor from which to be derived. Examples of simple original rivers may be seen in young plains, of which southern New Jersey furnishes a fair illustration. Examples of essentially original rivers may be seen also in regions of recent and rapid displacement, such as the Jura or the broken country of southern Idaho, where the directly consequent character of the drainage leads us to conclude that, if any rivers occupied these regions before their recent deformation, they were so completely extinguished by the newly made slopes that we see nothing of them now.

Once established, an original river advances through its long life, manifesting certain peculiarities of youth, maturity, and old age, by which its successive stages of growth may be recognized without much difficulty. For the sake of simplicity,



U. S. [illegible]

A LARGE YOUTHFUL VALLEY

Grand Canyon of the Yellowstone, Yellowstone National Park.

PLATE II

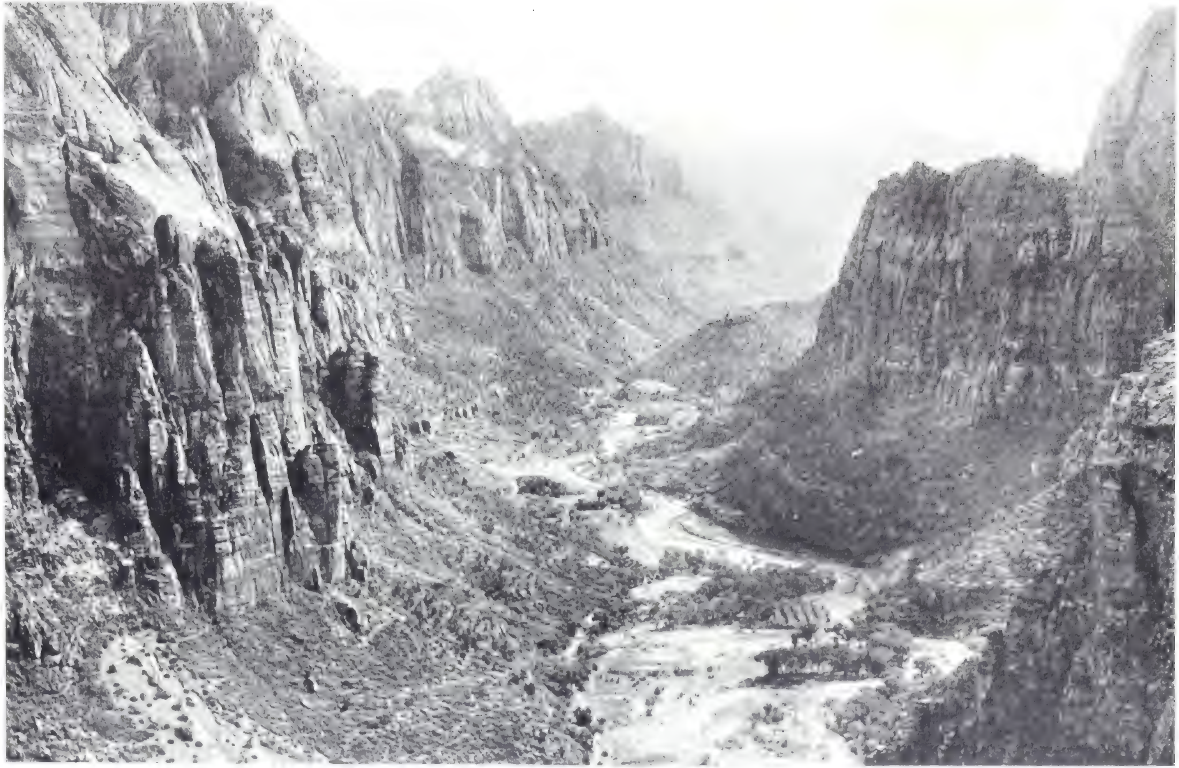


Photo Oliver J. Grimes

A MATURE VALLEY

Zion Canyon, Utah, in a semiarid region.

let us suppose the land mass, on which an original river has begun its work, stands perfectly still after its first elevation or deformation, and so remains until the river has completed its task of carrying away all the mass of rocks that rise above its base-level. The lapse of time will be called a cycle in the life of a river. A complete cycle is a long measure of time in regions of great elevation or of hard rocks; but whether or not any river ever passed through a single cycle of life without interruption we need not now inquire. Our purpose is only to learn what changes it would experience if it did thus develop steadily from infancy to old age without disturbance.

In its infancy the river drains its basin imperfectly, for it is then embarrassed by the original inequalities of the surface, and lakes collect in all the depressions. At such time the ratio of evaporation to rainfall is relatively large, and the ratio of transported land waste to rainfall is small. The channels followed by the streams that compose the river as a whole are narrow and shallow, and their number is small compared to that which will be developed at a later stage. The divides by which the side streams are separated are poorly marked, and in level countries are surfaces of considerable area and not lines at all. It is only in the later maturity of a system that the divides are reduced to lines by the consumption of the softer rocks on either side. The difference between constructional forms and these forms that are due to the action of denuding forces is in a general way so easily recognized that immaturity and maturity of a drainage area can be readily discriminated. In the truly infantile drainage system of the Red River of the North, the interstream areas are so absolutely flat that water collects on them in wet weather, not having either original structural slope or subsequently developed denuded slope to lead it to the streams. On the almost equally young lava blocks of southern Oregon, the well-marked slopes are as yet hardly channeled by the flow of rain down them, and the depressions among the tilted blocks are still undrained unfilled basins.

As the river becomes adolescent, its channels are deepened and all the larger ones descend close to base-level. If local contrasts of hardness allow a quick deepening of the downstream part of the channel, while the part next upstream resists erosion, a cascade or waterfall results; but, like the lakes of earlier youth, it is evanescent and endures but a small part of the whole cycle of growth; but the falls on the small headwater streams of a large river may last into its maturity, just as there are young twigs on the branch of a large tree. With the deepening of the channels, there comes an increase in the number of gulleys on the slopes of the channel; the gulleys grow into ravines and these into side valleys, joining their master streams at right angles (La Noë and Margerie). With their continued development the maturity of the system is reached; it is marked by an almost complete acquisition of every part of the original constructional surface by erosion under the guidance of the streams, so that every drop of rain that falls finds a way prepared to lead it to a stream and then to the ocean, its goal. The lakes of initial imperfection have long since disappeared; the waterfalls of adolescence have been worn back, unless on the still young headwaters. With the increase of the number of side streams, ramifying into all parts of the drainage basin, there is a proportionate increase in the surface of the valley slopes, and with this comes an increase in the rate of waste under atmospheric forces; hence it is at maturity that the river receives and carries the greatest load; indeed, the increase may be carried so far that the lower trunk stream, of gentle slope in its early maturity, is unable to carry the load brought to it by the upper branches, and therefore resorts to the temporary expedient of laying it aside in a flood plain. The level of the flood plain is sometimes built up faster than the small side streams of the lower course can fill their valleys, and hence they are converted for a little distance above their mouths into shallow lakes. The growth of the flood plain also results in carrying the point of junction of tributaries farther and farther downstream, and at last in turning lateral streams aside from the main stream, sometimes forcing them to follow independent courses to the sea (Lombardini). But although thus separated from the main trunk, it would be no more rational to regard such streams as independent rivers than it would be to regard the branch of an old tree, now fallen to the ground in the decay of advancing age, as an independent plant; both are detached portions of a single individual, from which they have been separated in the normal processes of growth and decay.

In the later and quieter old age of a river system, the waste of the land is yielded more slowly by reason of the diminishing slopes of the valley sides; then the headwater streams deliver less detritus to the main channel, which, thus relieved, turns to its postponed task of carrying its former excess of load to the sea, and cuts terraces in its flood plain, preparatory to sweeping it away. It does not always find the buried channel again, and perhaps settling down on a low spur a little to one side of its old line, produces a rapid or a low fall on the lower slope of such an obstruction (Penck). Such courses may be called locally superimposed.

It is only during maturity and for a time before and afterwards that the three divisions of a river, commonly recognized, appear most distinctly; the torrent portion being the still young headwater branches, growing by gnawing backwards at their sources; the valley portion proper, where longer time of work has enabled the valley to obtain a greater depth and width; and the lower flood-plain portion, where the temporary deposition of the excess of load is made until the activity of middle life is past.

"Maturity" seems to be a proper term to apply to this long enduring stage; for as in organic forms, where the term first came into use, it here also signifies the highest development of all functions between a youth of endeavor towards better work and an old age of relinquishment of fullest powers. It is the mature river in which the rainfall is best led away to the sea, and which carries with it the greatest load of land waste; it is at maturity that the regular descent and steady flow of the river is best developed, being the least delayed in lakes and least overhurried in impetuous falls.

Maturity past, and the power of the river is on the decay. The relief of the land diminishes, for the streams no longer deepen their valleys, although the hill-tops are degraded; and with the general loss of elevation, there is a failure of rainfall to a certain extent; for it is well known that up to certain considerable altitudes rainfall increases with height. A hyetographic and a hypsometric map of a country for this reason show a marked correspondence. The slopes of the headwaters decrease and the valley sides widen so far that the land waste descends from them more slowly than before. Later, what with failure of rainfall and decrease of slope, there is perhaps a return to the early imperfection of drainage, and the number of side streams diminishes as branches fall from a dying tree. The flood plains of maturity are carried down to the sea, and at last the river settles down to an old age of well-earned rest with gentle flow and light load, little work remaining to be done. The great task that the river entered upon is completed.

Flood Plains of Meandering Streams

The lower courses of large streams throughout the world have attracted a great deal of attention because the meanders, natural levees, and periodic floods that characterize them have exerted a great influence on the human development of these regions. Sir Charles Lyell (1797-1875), a celebrated Scottish geologist whose original work was greatly stimulated by extensive travels, writes as follows (Lyell,[1] 1860, pp. 255-256) concerning the course of the Po:

> *Course of the Po.*—The Po affords an instructive example of the manner in which a great river bears down to the sea the matter poured into it by a multitude of tributaries de-

---

[1] The edition of Lyell's *Principles of Geology* quoted here and elsewhere in this volume is the 9th edition, issued in 1853; but the page references are taken from a reprinting by Appleton dated 1860.

scending from lofty chains of mountains. The changes gradually effected in the great plain of Northern Italy, since the time of the Roman republic, are considerable. Extensive lakes and marshes have been gradually filled up, as those near Placentia, Parma, and Cremona, and many have been drained naturally by the deepening of the beds of rivers. Deserted river-courses are not unfrequent, as that of the Serio Morto, which formerly fell into the Adda, in Lombardy. The Po also itself has often deviated from its course, having after the year 1390 deserted part of the territory of Cremona, and invaded that of Parma; its old channel being still recognizable, and bearing the name Po Morto. There is also an old channel of the Po in the territory of Parma, called Po Vecchio, which was abandoned in the twelfth century, when a great number of towns were destroyed.

Artificial Embankments of Italian Rivers.—To check these and similar aberrations, a general system of embankment has been adopted; and the Po, Adige, and almost all their tributaries, are now confined between high artificial banks. The increased velocity acquired by streams thus closed in, enables them to convey a much larger portion of foreign matter to the sea; and, consequently, the deltas of the Po and Adige have gained far more rapidly on the Adriatic since the practice of embankment became almost universal. But, although more sediment is borne to the sea, part of the sand and mud, which in the natural state of things would be spread out by annual inundations over the plain, now subsides in the bottom of the river-channels; and their capacity being thereby diminished, it is necessary, in order to prevent inundations in the following spring, to extract matter from the bed, and to add it to the banks of the river. Hence it happens that these streams now traverse the plain on the top of high mounds, like the waters of aqueducts, and at Ferrara the surface of the Po has become more elevated than the roofs of the houses. The magnitude of these barriers is a subject of increasing expense and anxiety, it having been sometimes found necessary to give an additional height of nearly one foot to the banks of the Adige and Po in a single season.

The practice of embankment was adopted on some of the Italian rivers as early as the thirteenth century; and Dante, writing in the beginning of the fourteenth, describes, in the seventh circle of hell, a rivulet of tears separated from a burning sandy desert by embankments "like those which, between Ghent and Bruges, were raised against the ocean, or those which the Paduans had erected along the Brenta to defend their villas on the melting of the Alpine snows."

In 1845 Lyell made a trip down the Mississippi. The "steamboat days" were approaching their height, and the traveler had ample opportunity to study the habits of the great river. Some of his observations (Lyell, 1860, pp. 265-266) run thus:

Curves of the Mississippi.—The river traverses the plain in a meandering course, describing immense curves. After sweeping round the half of a circle, it is carried in a rapid current diagonally across the ordinary direction of its channel, to another curve of similar shape. Opposite to each of these, there is always a sand-bar, answering, in the convexity of its form, to the concavity of "the bend," as it is called. The river, by continually wearing these curves deep, returns, like many other streams before described, on its own track, so that a vessel in some places, after sailing for twenty-five or thirty miles, is brought round again to within a mile of the place whence it started. When the waters approach so near to each other, it often happens at high floods that they burst through the small tongue of land, and insulate a portion rushing through what is called the "cut-off," so that vessels may pass from one point to another in half a mile to a distance which it previously required a voyage of twenty miles to reach. As soon as the river has excavated the new passage, bars of sand and mud are formed at the two points of junction with the old bend, which is soon entirely separated from the main river by a continuous mud-bank covered with woods. The old bend then becomes a semicircular lake of clear water, inhabited by large gar-fish, alligators, and wild fowl, which the steamboats have nearly driven away from the main river. A multitude of such crescent-shaped lakes, scattered far and wide over the alluvial plain, the greater number of them to the west, but some of them also eastward of the Mississippi, bear testimony of the extensive wanderings of the great stream in former ages. For the last two hundred miles above its mouth the course of the river is much less winding than above, there being only in the whole of that distance one great curve, that called the "English Turn."

The Mississippi has been incorrectly described by some of the earlier geographers as a river running along the top of a long hill, or mound in a plain. In reality it runs in a valley, from 100 to 200 or more feet in depth, its banks forming long strips of land parallel to the course of the main stream, and to the swamps lying on each side. These extensive morasses, which are commonly well wooded, though often submerged for months continuously, are rarely more than fifteen feet below the summit level of the banks. The banks themselves are occasionally overflowed, but are usually above water for a breadth of about two miles. They follow all the curves of the great river, and near New Orleans are raised artificially by embankments (or levees), through which the river when swollen sometimes cuts a deep channel (or crevasse), inundating the adjoining low lands and swamps, and not sparing the lower streets of the great city.

The cause of the uniform upward slope of the river-bank above the adjoining alluvial plain is this: when the waters charged with sediment pass over the banks in the flood season, their velocity is checked among the herbage and reeds, and they throw down at once the coarser and more sandy matter with which they are charged. But the fine particles of mud are carried farther on, so that at the distance of about two miles, a thin film of fine clay only subsides, forming a stiff unctuous black soil, which gradually envelops the bases of trees growing on the borders of the swamps.

The bends and meanders described above have been utilized more than once in military strategy. They played a part in the siege of Vicksburg in 1863. The town was located on the outside of a large meander. Grant planned to have his engineers dig a canal across the neck of the curve in order to divert the Mississippi and isolate the town. The attempt failed, however; and it was for other reasons that Vicksburg later fell.

Samuel L. Clemens (Mark Twain) was a trained observer of river phenomena, having spent years as a pilot on the Mississippi at the height of the "steamboat days." His observations are renowned chiefly for their humor, but they are as accurate as they are amusing. His *Life on the Mississippi* (Mark Twain, 1874, Chapter I) opens thus:

> The Mississippi is well worth reading about. It is not a commonplace river, but on the contrary is in all ways remarkable. Considering the Missouri its main branch, it is the longest river in the world—four thousand three hundred miles. It seems safe to say that it is also the crookedest river in the world, since in one part of its journey it uses up one thousand three hundred miles to cover the same ground that the crow would fly over in six hundred and seventy-five. It discharges three times as much water as the St. Lawrence, twenty-five times as much as the Rhine, and three hundred and thirty-eight times as much as the Thames. No other river has so vast a drainage-basin; it draws its water-supply from twenty-eight states and territories; from Delaware on the Atlantic seaboard, and from all the country between that and Idaho on the Pacific slope—a spread of forty-five degrees of longitude. The Mississippi receives and carries to the Gulf water from fifty-four subordinate rivers that are navigable by steamboats, and from some hundreds that are navigable by flats and keels. The area of its drainage basin is as great as the combined areas of England, Wales, Scotland, Ireland, France, Spain, Portugal, Germany, Austria, Italy, and Turkey; and almost

all this wide region is fertile; the Mississippi Valley, proper, is exceptionally so.

It is a remarkable river in this: that instead of widening toward its mouth, it grows narrower, grows narrower and deeper. From the junction of the Ohio to a point half-way down to the sea, the width averages a mile in high water; thence to the sea, the width steadily diminishes, until, at the "Passes," above the mouth, it is but little over half a mile. At the junction of the Ohio the Mississippi's depth is eighty-seven feet; the depth increases gradually, reaching one hundred and twenty-nine just above the mouth.

The difference in rise and fall is also remarkable—not in the upper, but in the lower river. The rise is tolerably uniform down to Natchez (three hundred and sixty miles above the mouth)—about fifty feet. But at Bayou La Fourche the river rises only twenty-four feet; at New Orleans only fifteen, and just above the mouth only two and one-half.

An article in the New Orleans *Times-Democrat,* based upon reports of able engineers, states that the river annually empties four hundred and six million tons of mud into the Gulf of Mexico—which brings to mind Captain Marryat's rude name for the Mississippi—"the Great Sewer." This mud, solidified, would make a mass a mile square and two hundred and forty-one feet high.

The mud deposit gradually extends the land—but only gradually; it has extended it not quite a third of a mile in the two hundred years which have elapsed since the river took its place in history.

The belief of the scientific people is that the mouth used to be at Baton Rouge, where the hills cease, and that the two hundred miles of land between there and the Gulf was built by the river. This gives us the age of that piece of country, without any trouble at all—one hundred and twenty thousand years. Yet it is much the youthfulest batch of country that lies around there anywhere.

The Mississippi is remarkable in still another way—its disposition to make prodigious jumps by cutting through narrow necks of land, and thus straightening and shortening itself. More than once it has shortened itself thirty miles at a single jump!

These cut-offs have had curious effects: they have thrown several river towns out into the rural districts, and built up sand-bars and forests in front of them. The town of Delta used to be three miles below Vicksburg; a recent cut-off has radically changed the position, and Delta is now two miles above Vicksburg.

Both of these river towns have been retired to the country by that cut-off. A cut-off plays havoc with boundary lines and jurisdictions: for instance, a man is living in the state of Mississippi to-day, a cut-off occurs to-night, and to-morrow the man finds himself and his land over on the other side of the river, within the boundaries and subject to the laws of the state of Louisiana! Such a thing, happening in the upper river in the old times, could have transferred a slave from Missouri to Illinois and made a free man of him.

The Mississippi does not alter its locality by cut-offs alone: it is always changing its habitat bodily—is always moving sidewise. At Hard Times, Louisiana, the river is two miles west of the region it used to occupy. As a result, the original site of that settlement is not now in Louisiana at all, but on the other side of the river, in the state of Mississippi. Nearly the whole of that one thousand three hundred miles of old Mississippi River which La Salle floated down in his canoes, two hundred years ago, is good solid dry ground now. The river lies to the right of it, in places, and to the left of it in other places.

Although the Mississippi's mud builds land but slowly, down at the mouth, where the Gulf's billows interfere with its work, it builds fast enough in better protected regions higher up: for instance, Prophet's Island contained one thousand five hundred acres of land thirty years ago; since then the river has added seven hundred acres to it.

In another place Mark Twain describes the cutting off of meanders, with some corollaries of his own invention. His remarks about the Silurian Period must not be taken too seriously. He begins (Mark Twain, 1874, Chapter XVII) by discussing

> . . . one of the Mississippi's oddest peculiarities—that of shortening its length from time to time. If you will throw a long, pliant apple-paring over your shoulder, it will pretty fairly shape itself into an average section of the Mississippi River; that is, the nine or ten hundred miles stretching from Cairo, Illinois, southward to New Orleans, the same being wonderfully crooked, with a brief straight bit here and there at wide intervals. The two-hundred-mile stretch from Cairo northward to St. Louis is by no means so crooked, that being a rocky country which the river cannot cut much.
>
> The water cuts the alluvial banks of the "lower" river into deep horseshoe curves; so deep, indeed, that in some places if you were to get ashore at one extremity of the horseshoe and walk across the neck, half or three-quarters of a mile, you could sit down and rest a couple of hours while your steamer was coming around the long elbow at a speed of ten miles an hour to take you on board again. When the river is rising fast, some scoundrel whose plantation is back in the country, and therefore of inferior value, has only to watch his chance, cut a little gutter across the narrow neck of land some dark night, and turn the water into it, and in a wonderfully short time a miracle has happened: to wit, the whole Mississippi has taken possession of that little ditch, and placed the countryman's plantation on its bank (quadrupling its value), and that other party's formerly valuable plantation finds itself away out yonder on a big island; the old watercourse around it will soon shoal up, boats cannot approach within ten miles of it, and down goes its value to a fourth of its former worth. Watches are kept on those narrow necks at needful times, and if a man happens to be caught cutting a ditch across them the chances are all against his ever having another opportunity to cut a ditch.

Pray observe some of the effects of this ditching business. Once there was a neck opposite Port Hudson, Louisiana, which was only half a mile across in its narrowest place. You could walk across there in fifteen minutes; but if you made the journey around the cape on a raft, you traveled thirty-five miles to accomplish the same thing. In 1722 the river darted through that neck, deserted its old bed, and thus shortened itself thirty-five miles. In the same way it shortened itself twenty-five miles at Black Hawk Point in 1699. Below Red River Landing, Raccourci cut-off was made (forty or fifty years ago, I think). This shortened the river twenty-eight miles. In our day, if you travel by river from the southernmost of these three cut-offs to the northernmost, you go only seventy miles. To do the same thing a hundred and seventy-six years ago, one had to go a hundred and fifty-eight miles—a shortening of eighty-eight miles in that trifling distance. At some forgotten time in the past, cut-offs were made above Vidalia, Louisiana, at Island 92, at Island 84, and at Hale's Point. These shortened the river, in the aggregate, seventy-seven miles.

Since my own day on the Mississippi, cut-offs have been made at Hurricane Island, at Island 100, at Napoleon, Arkansas, at Walnut Bend, and at Council Bend. These shortened the river, in the aggregate, sixty-seven miles. In my own time a cut-off was made at American Bend, which shortened the river ten miles or more.

Therefore the Mississippi between Cairo and New Orleans was twelve hundred and fifteen miles long one hundred and seventy-six years ago. It was eleven hundred and eighty after the cut-off of 1722. It was one thousand and forty after the American Bend cut-off. It has lost sixty-seven miles since. Consequently, its length is only nine hundred and seventy-three miles at present.

Now, if I wanted to be one of those ponderous scientific people, and "let on" to prove what had occurred in the remote past by what had occurred in a given time in the recent past, or what will occur in the far future by what has occurred in late years, what an opportunity is here! Geology never had such a chance, nor such exact data to argue from! Nor "development of species," either! Glacial epochs are great things, but they are vague—vague. Please observe:

In the space of one hundred and seventy-six years the Lower Mississippi has shortened itself two hundred and forty-two miles. That is an average of a trifle over one mile and a third per year. Therefore, any calm person, who is not blind or idiotic, can see that in the Old Oölitic Silurian Period, just a million years ago next November, the Lower Mississippi River was upward of one million three hundred thousand miles long, and stuck out over the Gulf of Mexico like a fishing-rod. And by the same token any person can see that seven hundred and forty-two years from now the Lower Mississippi will be only a mile and three-quarters long, and Cairo and New Orleans will have joined their streets together, and be plodding comfortably along under a single major and a mutual board of aldermen. There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact.

When the water begins to flow through one of those ditches I have been speaking of, it is time for the people thereabouts to move. The water cleaves the banks away like a knife. By the time the ditch has become twelve or fifteen feet wide, the calamity is as good as accomplished, for no power on earth can stop it now. When the width has reached a hundred yards, the banks begin to peel off in slices half an acre wide. The current flowing around the bend traveled formerly only five miles an hour; now it is tremendously increased by the shortening of the distance. I was on board the first boat that tried to go through the cut-off at American Bend, but we did not get through. It was toward midnight, and a wild night it was—thunder, lightning, and torrents of rain. It was estimated that the current in the cut-off was making about fifteen or twenty miles an hour; twelve or thirteen was the best our boat could do, even in tolerably slack water, therefore perhaps we were foolish to try the cut-off. However, Mr. Brown was ambitious, and he kept on trying. The eddy running up the bank, under the "point," was about as swift as the current out in the middle; so we would go flying up the shore like a lightning express-train, get on a big head of steam, and "stand by for a surge" when we struck the current that was whirling by the point. But all our preparations were useless. The instant the current hit us it spun us around like a top, the water deluged the forecastle, and the boat careened so far over that one could hardly keep his feet. The next instant we were away down the river, clawing with might and main to keep out of the woods. We tried the experiment four times. I stood on the forecastle companionway to see. It was astonishing to observe how suddenly the boat would spin around and turn tail the moment she emerged from the eddy and the current struck her nose. The sounding concussion and the quivering would have been about the same if she had come full speed against a sand-bank. Under the lightning flashes one could see the plantation cabins and the goodly acres tumble into the river, and the crash they made was not a bad effort at thunder. Once, when we spun around, we only missed a house about twenty feet that had a light burning in the window, and in the same instant that house went overboard. Nobody could stay on our forecastle; the water swept across it in a torrent every time we plunged athwart the current. At the end of our fourth effort we brought up in the woods two miles below the cut-off; all the country there was overflowed, of course. A day or two later the cut-off was three-quarters of a mile wide, and boats passed up through it without much difficulty, and so saved ten miles.

The constant channel-shifting that goes on in large rivers results in frequent—sometimes daily—changes for which river pilots must be constantly on the alert lest their steamboats go aground. Lyell (1860, p. 267) has recorded changes of this kind in the Mississippi and in the Ganges:

Waste of the Banks.—It has been said of a mountain torrent, that "it lays down what it will remove, and removes what it has laid down"; and in like manner the Mississippi, by the continual shifting of its course, sweeps away, during a great portion of the year, considerable tracts of alluvium, which were gradually accumulated by the overflow of former years, and the matter now left during the spring-floods will be at some future time removed. After the flood season, when the river subsides within its channel, it acts with destructive force upon the alluvial banks, softened and diluted by the recent overflow. Several acres at a time, thickly covered with wood, are precipitated into the stream; and large portions of the islands are frequently swept away.

"Some years ago," observes Captain Hall, "when the Mississippi was regularly surveyed, all its islands were numbered, from the confluence of the Missouri to the sea; but every season makes such revolutions, not only in the number, but in the magnitude and situation of these islands, that this enumeration is now almost obsolete. Sometimes large islands are entirely melted away; at other places they have attached themselves to the main shore, or, which is the more correct statement, the interval has been filled up by myriads of logs cemented together by mud and rubbish."

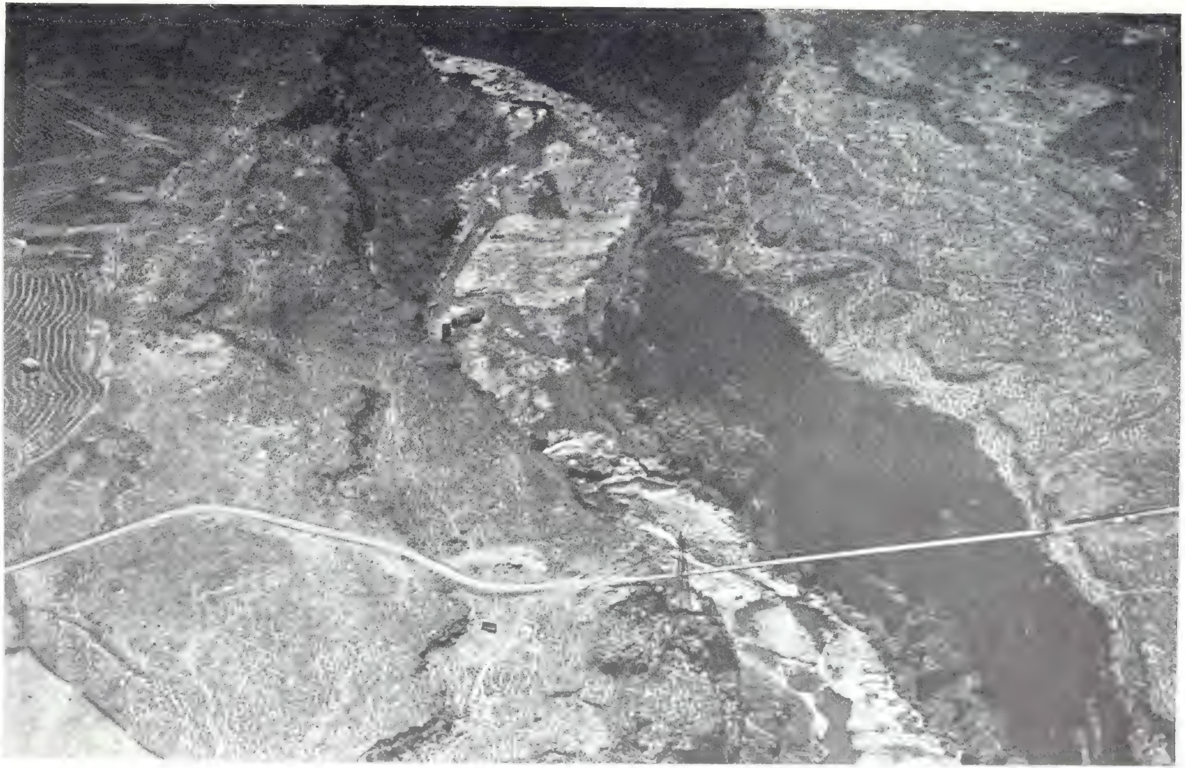
In another place Lyell (1860, p. 277) describes the continuous erosion and deposition that characterize the lower reaches of great rivers:

Islands Formed and Destroyed.—Major R. H. Colebrooke, in his account of the course of the Ganges, relates examples of the rapid filling up of some of its branches, and the excavation of new channels, where the number of square miles of soil removed in a short time (the column of earth being 114 feet high) was truly astonishing. Forty square miles, or 25,600 acres, are mentioned as having been carried away, in one place, in the course of a few years. The immense transportation of earthy matter by the Ganges and Brahmapootra is proved by the great magnitude of the islands formed in their channels during a period far short of that of a man's life. Some of these, many miles in extent, have originated in large sandbanks thrown up round the points at the angular turning of the rivers, and afterwards insulated by breaches of the streams. Others, formed in the main channel, are caused by some obstruction at the bottom. A large tree, or a sunken boat, is sometimes sufficient to check the current, and cause a deposit of sand, which accumulates till it usurps a considerable portion of the channel. The river then undermines its banks on each side, to supply the deficiency in its bed, and the island is afterwards raised by fresh deposits during every flood. In the great gulf below Luckipour, formed by the united waters of the Ganges and Megna, some of the islands, says Rennell, rival in size and fertility the Isle of Wight. While the river is forming new islands in one part, it is sweeping away old ones in others. Those newly formed are soon overrun with reeds, long grass, the Tamarix Indica, and other shrubs, forming impenetrable thickets, where the tiger, the rhinoceros, the buffalo, deer, and other wild animals take shelter. It is easy, therefore, to perceive that both animal and vegetable remains may occasionally be precipitated into the flood, and become imbedded in the sediment which subsides in the delta.

The Red River Rafts

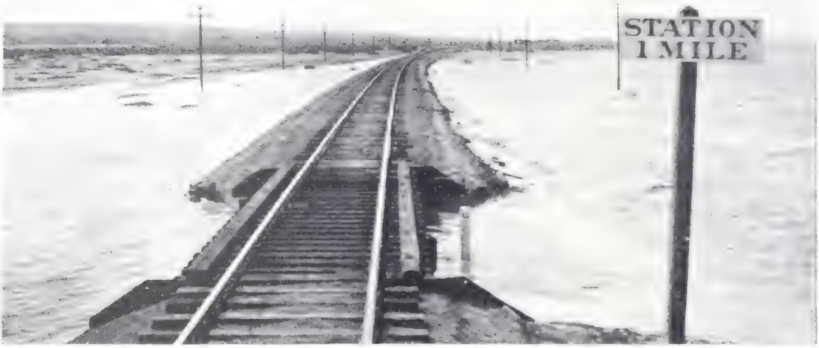
The course of Red River where it sluggishly wanders down its flood plain through northwestern Louisiana is remarkable in that it is bordered by a number of large shallow lakes. These lakes are not the crescentic oxbows which might be expected in such a situation; they are broad and irregular in outline, and several of them moreover occupy the center of the valley while the river turns aside and hugs the low fringing bluffs. These lakes are far from inviting. The dense growths of trees around their shores are encumbered with prostrate trunks and branches, dead and decaying. Luxuriant trailing vines and creepers add to the tangle underfoot. The lake borders themselves are swampy and treacherous, and the open expanse of lake water is dotted

PLATE III



A STEEP-SIDED CANYON

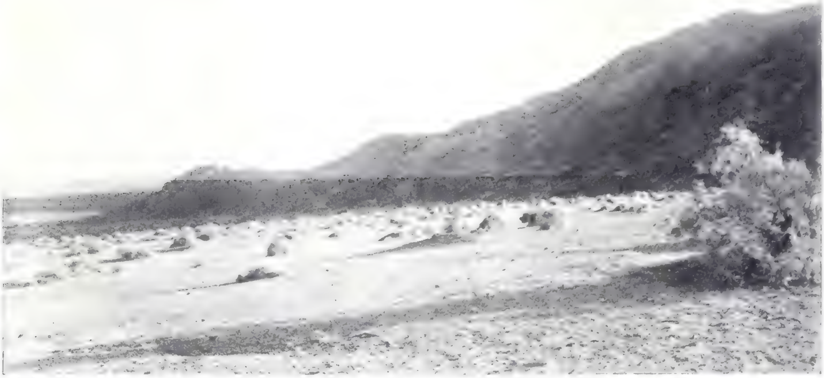
Cut into hard basalt. Snake River near Hansen, Idaho.



U. S. Geological Survey

A. THE RISE OF THE SALTON SEA

Line of the Southern Pacific Railroad, 200 feet below sea level, flooded in 1906.



U. S. Geological Survey

B. ANCIENT WATERLINE AROUND THE SALTON BASIN here and there with the whitened, branchless trunks of cypress, pine, and gum trees killed by drowning, but rooted still in the mucky bottoms.

The fact that the water-killed trees are still standing at once suggests that the lakes were not formed long ago. Let us examine them more closely for clues as to their origin. A circuit of any of the shores is a slow and difficult undertaking, but it reveals a striking fact. At the southern or downstream end of each lake, there are no large trees. The twining weeds and vines are dominated by nothing larger than small willows and cottonwoods, and they are growing on a partly concealed floor of *logs*. The footing becomes insecure, and tiny patches of open water appear, irregularly spaced within this strange mosaic of logs lying in all positions and at all angles. This log area, already supporting a flourishing growth, may be several miles in length. It is a log jam, which has dammed the river and formed a lake. In the early part of the nineteenth century, when this wilderness was explored, there were more log-jam lakes than there are at present. The settlers called the dams "rafts." By watching the river's habits, they came gradually to understand how the lakes were made. They noticed after each flood that quantities of timber caved into the river as the banks were undercut. They saw these trees catch on the bars, and they saw their branches broken from them. Not infrequently, a number of floating logs became jammed in a narrow bend or behind a group of snags. Once firmly set, a jam of this sort collected everything that floated down the river. Water-soaked logs sank to the bottom, others were forced in over them, silt filtered through between them, and the river was blocked. The water level rose until it found a low outlet at the side of this basin, and there, rushing through, it excavated a new channel, flowed down the gentle slope of the natural levees to the bluffs at the edge of the broad valley, and continued on its way. By the development of similar channels upstream, some of the lakes were completely isolated from the parent river. The rate at which these rafts accumulated by the addition of logs from upstream is illustrated by a report of Captain Henry M. Shreve (for whom the city of Shreveport was named) dated 1826. Writing of the obstruction north of Natchitoches, he said: "Raft has accumulated five miles since last May. Unusually high freshet having brought down three times the usual amount of material." In 1833 the Government undertook to improve Red River for navigation, and under the direction of Captain Shreve the destruction of the rafts was begun. The compound series of jams was 160 miles in length. The entire task of removing the logs and clearing the river took more than forty years and would have taken longer if most of the logs had not been thoroughly rotten. Other rafts were later destroyed, dangerous snags and fragments of the former rafts were cleared up, lake outlets through the old levees were closed, and the river was thus forced back into much of its old channel. It has thus been forced to cut down through the deltas it had deposited in the raft-lakes, and this has resulted in readjustments of the gradient throughout this part of its course. Since the removal of the rafts the lakes have been gradually shrinking and are likely in time to disappear. But while they remain, they record the notable history of the river that dammed itself with its own flotsam.

Floods

The recurrent risings of large streams which we call floods, have many consequences of importance to human activity. The means by which floods are caused are interestingly set forth in a brief discussion by J. W. Powell (1896, pp. 7-9):

> Stream channels are the aqueducts by which the water not evaporated runs off. The streams cut their own channels. Where there is more water to be carried, the channel is made deeper or wider (one or both), and for this purpose there is more water to do the work. But the channels will not hold all the water of great rainstorms: hence floods come, for a flood is the flow of a stream over the banks of its channel. If a stream cuts its own channel, and if the greater the amount of water the greater the size of the channel, other things being equal, why is it that floods come? This question must be answered by explaining the manner in which stream channels are choked. There are many minor ways by which they are obstructed, but most of these may be neglected, as they are

of small importance; but the two principal methods require attention.

By the first method, a small stream chokes a larger one; and by the second method, a stream chokes itself. Let us understand the first one.

Consider a stream without tributaries. Suppose that all the water carried by it is derived from one source, some mammoth spring with a constant supply, and that no water is added to its volume on its way to the sea. Under such circumstances, the stream cuts its own channel from source to outlet large enough to carry the volume of water, and it never overflows its bank. Now suppose another stream is turned into it, and that this tributary drains a region of country where there are intermittent rains. When the rains come, the new stream has a large volume of water loaded with mud washed from the hills and valleys, where the rains are caught which supply its volume. When the muddy stream enters the river, the sands and gravels are in part deposited below the junction. This forms a dam or obstruction, and tends to cause a flood in the main stream above the junction. Let other streams be turned into the main river; and wherever such a lateral stream comes in, a dam is constructed below the junction. Now, the river has a series of dams constructed along its course, each one of which tends to cause the river to overflow its banks. The dams constructed in this manner are washed out and built again, and washed out and built again, from time to time. Sometimes a series of these dams has been constructed just before some great rainfall, so that the stream is in no condition to carry the greater supply and a flood results. It is in this manner that large streams are choked by smaller ones, and that floods arise therefrom.

Now, it must be understood how streams choke themselves. When the waters are low in any stream, they are clear. When the waters are high, they are muddy, for the rains which cause the increase of volume wash the surface soil into the streams. Rain thus makes the river muddy. The mud brought into the stream, being heavier than the water, sinks to the bottom. When the waters are swift, but little mud falls; where the waters are quiet, much mud falls. The waters are swifter around the outside of a bend, and slower on the inside of it. From this slower water the mud is deposited, so the bank of the inner curve grows. As the bank grows, the water is pushed over against the other bank on the outer side of the curve, where its flow is increased in velocity so as to cut the bank, and load more material upon the stream. The new load is in part thrown down again at the next bend on the opposite side, where the water is comparatively still. The first curve increases itself by building up on the inside, and cutting down on the outside. In the same manner the second curve is increased in the opposite direction by building up on one side, and cutting down on the other. So it is that rivers not only cut their own channels, but change their own courses from time to time. In this change the stream is constantly depositing new obstructions, forming dams, which are known as *bars;* so that, when some great rainstorm comes after such obstructions have been built, the water cannot be carried away by the channel, and it overflows its banks, and there is a great flood.

So one stream obstructs another, and a stream obstructs itself. All floods are ultimately caused by obstruction, and obstructions are chiefly caused by one or both of the methods described.

Thus far we have considered the regimen of streams in a state of nature. When man comes with the arts of civilization to change the surface of the earth, additional disturbing factors enter into the problem. Man plows the fields, and the side streams carry additional amounts of detritus, and the obstructing dams are multiplied and enlarged; he changes the courses of the smaller streams, and thus introduces disturbing elements into the larger. For the purpose of obtaining water powers, he builds dams, and again changes and introduces new elements into the regimen. Many of the things that man does upon the surface of the earth have an influence upon the run-off, and generally increase the violence of floods; but in lands where irrigation is practiced the waters are taken away from their natural channels and spread over the soils, to be re-evaporated into the heavens; and thus the streams are made smaller, and the floods are diminished or entirely prevented.

The Floods of San Juan River

The quantity of silt carried by streams in flood in arid regions is tremendous. Parties of geologists have been sent out at various times by the U. S. Geological Survey to make trips by boat down the streams of the arid West, in order to study the geology of the valleys and the behavior of the streams. Some of these expeditions, especially those that descended the Colorado, have been difficult and even perilous. The report (Miser, 1924, p. 57) on an expedition down San Juan River in southeastern Utah includes this passage:

> The quantity of silt is lowest during low stages of the river, and also during the early summer floods that are caused by melting snows in the San Juan Mountains of Colorado. Then the water assumes a milky color. It never gets clear. Between July 18 and October 3, 1921, it was comparatively free from silt during only two periods—on July 18 and 19 and from September 10 to 30—but even then every cup of water taken from the river would contain sand grains and fine silt. At all other times, especially during flood stages, the river was very muddy.
>
> The usual color of the silt-laden stream is gray to buff, but it changes to a brick-red during the falling stages of floods. On August 1 a flood in the river passed the foot of the Honaker trail, where the Trimble party was camped. The highest stage of the flood—6 feet—was reached at 7 a.m. Between that time and the middle of the afternoon the river fell 3 to 4 feet, and in so doing assumed a brick-red color and ran like a stream of molten metal, whose entire surface was covered by waves of large and small size. While the river was flowing

like metal the fish came to the surface in an exhausted condition and swam feebly in the eddies, with their dorsal fins sticking out of the water. The enormous load of fine red silt in the water had apparently in some way prevented the fish from obtaining the usual supply of oxygen. Many of the exhausted fish were caught by members of the party with bare hands, and many were washed ashore by waves to perish. After two or three hours the fish revived and disappeared from the surface. Bert Loper, boatman of the party, who lived on Colorado River for many years, says such floods have been known to last long enough to kill thousands of fish.

The Nita Crevasse

In March, 1890, while the Mississippi was in flood, there occurred a break in the levee system on the outside of a bend at the Nita Plantation, nearly fifty miles above New Orleans. The flood water overflowed through this "crevasse" and reached the Gulf independently of the main channel at a point opposite the eastern shore of Mississippi. Events such as this have led geologists to understand how the independent channels of the lower Mississippi have developed—by the discharge of temporary distributaries from the flooded main river. The following account, which appeared before this fact was widely known (Johnson, 1891, pp. 20-25), discusses the Nita crevasse.

The first break began March 13, 1890; yet it was not until March 22, nine days later, that the water came through the south pass of Manchac (the bayou or strait connecting Lake Maurepas with Lake Pontchartrain), and two weeks more passed before Lake Maurepas overflowed the lowlands to the northeastward sufficiently to threaten the track of the Illinois Central railway; and it was not until April 13th, or a month after the break, that this railway was covered so deeply as to stop the running of trains. The water now quickly spread over the whole of the flat country from the 28-mile post north of New Orleans to the 46-mile post, or to within one and a half miles of Ponchatoula station, and trains ceased to pass over this line till June 23. The greatest height attained here by the river water was only eight and a half feet above mean tide, or the ordinary low-water stage of Manchac.

Ordinary maps do not show the well-known fact that the banks of the river, of the bayous, and of lakes Maurepas, Pontchartrain, and Borgne are higher than the back swamps immediately adjoining, and that the Mississippi River at the Nita crevasse is (by estimate) twenty-one feet above the swamps about Lake Maurepas. It is reasonable to suppose that in locating the Illinois Central railway the highest ground was selected; yet until surveys were actually made it was not suspected that the lowest ground is not the banks of Manchac, nor yet the quaking bogs to the south of it, but the apparently firm land of the "pine meadows" or prairies to the north, between the bayou and Ponchatoula. . . .

At the break the immediate action was destructive. Except where there was little or no current there was no deposition of sediment, although in the wake of stranded houses and other obstructions elongated banks or ridges of sand and mud were formed, and these included many fragments of the wrecked houses and mills. In one case many iron implements were found imbedded in the sand and silt with leaves, sticks and other debris. A part of this silty sediment, but with less and less of sand, was deposited eastward along the bayous and timbered bottoms between the crevasse and Lake Maurepas. On the large flat prairie or pine meadow towards Ponchatoula, the water, deep as it was, left no sand, but only a fine, impalpable, yellowish or bluish-brown clay, such as constitutes the basis of the pine meadows from Ponchatoula to Escatawpa River. . . .

And thus the Nita crevasse, with its floods of muddy water seeking an outlet directly into Mississippi Sound, and with the destruction or displacement of aquatic life over a large area, illustrates an episode in the development of the lower Mississippi region such as has been enacted more than once in the past, and illustrates at the same time the manner in which the development of the region has been accomplished. In all the series of events and deposits, from the first stages of the Port Hudson and Pontchartrain to the uppermost clays of these formations and the sands and gravels at the base of the loess, to the stages of the loess at Bayou Sara, of the loam at Port Hickey and Baton Rouge, of the brick clays on Amite and Pearl rivers, and of the Biloxi sands, down to the effects of the Nita crevasse, the method, the system and the agent have been but one; the dates of action and doubtless the degrees of energy have varied, but the source of the material and power has always been and is to-day the same—the great river from the north.

The Flood Problem

The destructive flood that occurred in the Mississippi in the spring of 1927 reopened the periodic question of flood prevention. One point of view was voiced in a popular editorial that appeared when the flood was at its height. Parts of it (*Can Floods be Prevented? The New Republic,* May 18, 1927) are reproduced here.

It is only natural that people should be asking whether such disasters as this are in fact preventable. On this point, it can be said definitely that the measures taken in the past have certainly been inadequate. These have consisted almost exclusively of building levees, on which about $168,000,000 has been spent by the federal government since 1879. Every time a bad flood has occurred—and they have come at an average interval of only six years—the levees have been built higher. Yet almost every time, the next flood has broken through or has gone over the top of the dike. This has been true of the three great floods of recent years: those of 1912, 1922, and 1927. It is inevitable that people should begin to ask whether the federal and state authorities, who are pinning all their hopes to the levee system, are not making a mistake—whether their attempt at a cure does not in reality aggravate the disease?

Before the coming of the white man, the Mississippi frequently overflowed its banks, in the regions near its mouth. A vast area went under water temporarily, with the melting of the snows in the north and the coming of the spring rains. Not only was this true, but the river had its own "spillways," or extra outlets to the sea, through which the surplus water ran off. The struggle with the river in the past century, and particularly since 1879, has been a record of continuing attempts to reclaim lands in the flood area. The natural spillways have been cut off. The levees, of which there are now 2,500 miles, have been built ever higher and stronger. The fight to narrow the area which is subject to flood has been a successful one. Yet it stands to reason that if the same amount of water is made to follow a narrower course it will run in a stream proportionately deeper. A small part of this added depth with be accounted for by the scouring effect which the more rapid current will have upon the main channel; but most of it will be represented in the form of increased depth of water with corresponding likelihood that the levees will be broken or submerged. This would be true, even were the volume of water the same as in former years. But there is, unfortunately, the best of reason to believe that the volume of water in flood times has been enormously augmented as a result of the short-sighted policy pursued in the northern states.

Such a flood as we are now experiencing takes place when we have heavy rain, or rapid melting of snow, or both, throughout a large part of the 1,200,000 square miles of the Mississippi Valley. That has been the case this year, and in every preceding year of high water. However, before the Valley had been settled, there were several factors, operating to hold back the flood waters, which are no longer so effective as they once were. Along the western slopes of the Appalachians, where the Ohio and its tributaries rise, there were extensive forests. In several ways these served to retard the creation of torrents of water. The air above a forest is cooler, producing frequent slight precipitation instead of an occasional deluge. The fall of the water is slackened by its striking the leaves and by the necessity of its working through the spongy mass of dead vegetable matter which covers and interpenetrates the top layer of the soil. The roots hold the earth together and prevent its washing down into gullies which form a convenient channel for the flood current.

Further to the west, where most of the countryside consisted of open plains, the margins of rivers were heavily wooded, and this timber served the same purpose as the forests. The plains, before they had been broken by the plow, were covered with a rich, heavily matted vegetation. Even the most torrential rains were unable to get through to the roots, loosen the soil and wash it away. There were, moreover, numerous swamps and marshy places which acted as natural reservoirs in periods of excessive precipitation, holding the waters until they drained off slowly in the course of weeks, or evaporated. Finally, there were many lakes, which also caught and impounded much of the surplus water.

The editorial concludes that deforestation, over-grazing, unscientific plowing, the draining of lakes and swamps, and the effect of forest fires throughout the tributary areas are to blame. It holds that the system of artificial levees in use on the lower Mississippi does not afford adequate protection to the inhabitants and property in the river basin.

The argument as a whole is based on beliefs that are not held universally. It is the contention of the Mississippi River Commission that the bed of the river is not rising either as a result of the stream's inability to carry its load of sediment or in consequence of the building of levees. The level of the river does not ordinarily rise higher than the surface of the surrounding lowlands; it is only during times of flood that the restraining levees are necessary to prevent overflow by the river. The photograph (Plate V, B) therefore represents flood conditions rather than low-water conditions. The Commission has pointed out further that the repeated heightening of the levees along the Mississippi has not been self-necessitated; that is, each addition required by silting up of the river bed attendant upon previous building. The successive increases in the heights of the levees are a part of the original plan adopted when the Commission was organized.

Many engineers, however, believe that a single line of levees such as are now maintained, is inadequate to keep the Mississippi within its banks during times of flood. The following paragraphs are extracted from a technical article, whose author (Freeman, 1927, pp. 95-102) is an engineer:

> Forty years ago, following the building of the Eads jetties and the experience of many floods, the Mississippi River Commission was formed, and it has practically had charge of the problems of flood control ever since. . . .
>
> The Commission . . . seems to have settled down to a firmly established policy in accordance with which most of the construction work on river control has been done. For its foundation this had three chief items. One was that the so-called levee system was the correct system. High levees were to be made continuous along the river, confining floods to about a mile in width instead of permitting them to spread out thirty miles more or less in the state of nature for hundreds of miles below Memphis. It was concluded to be probable that the river, being so confined, would naturally dig its channel deeper, giving the water a better chance to flow off, or that whatever happened the sediments would not accumulate within this narrowed channel to an extent that would compel dikes to be continually built higher.
>
> The second main item of policy was the protection of caving river banks along concave shores of river bends. This continuous caving and shifting of channel in the state of nature, cuts away nearly a square mile of land each year. These caving banks were to be protected by building revetments of submerged "mattresses" composed of small willow trees and branches held down by small boulders. Levees were to be built and paid for in coöperation with the localities benefited, but revetment was to be paid for wholly by the Federal Government as an aid to navigation, all to be built as fast as

Congress provided the money. The third item was that navigation channels were to be dredged through the gravel bars, which nature builds up after each great flood across the river where its bends reverse their curvature. Thus levees, revetments, and dredgings have been the three main items in the settled policies of Mississippi River control. . . .

There has in all been 1,500 miles or more of levee built to a height three feet above the highest flood of record, according to a program which was more than three-fourths complete when the recent flood came. Where thirty years ago any flood of more than ordinary height broke many dikes and flooded many thousands of acres, so the possibilities of having to move out suddenly to higher ground were constantly in mind, conditions had been so improved by completion of higher levees that in the last great flood before the 1927 one, that of 1922, the levee system performed with really wonderful efficiency, and presented only two or three serious breaks in its entire line of more than 1,500 miles. Meanwhile, because of better levees the reclamation of swamp lands for agriculture proceeded rapidly and values per acre were vastly increased. Much of the recent distress is due to forgetfulness of the danger of flooding that has always hung over these reclaimed river bottom lands and probably always will continue.

Some few people are now in a hurry to condemn the levee system, where really it is entitled to abundant praise. There is a bright picture of the wonderfully successful protection by the levees in what happened during the great flood of 1922. The 1922 flood rose within a foot or two of the height of the present flood, and in all of more than 1,500 miles of levees there were only two serious breaks, although there were several narrow escapes. The levees as they stood in 1922 protected more than nine-tenths of the land that was relying on them for protection. Considering a period of more than ten years, levees have protected everything except ten per cent of the land flooded in one year out of the ten. That figures out to be a "batting average" of ninety-nine per cent; which really is doing wonderfully well.

There is now a loud outcry "Complete the levees."

Completing a single line of levees along each shore to full height and thickness *can never fully protect the low lands behind them.*

The dangers that remain after levees have been built to full height and standard thickness, have been so largely overlooked, during the recent popular discussion, that it seems to me now important to devote some time to these particular dangers of deep under-cutting, a case of which may occur almost anywhere without warning, and may over night get beyond control so as to inundate more than 1,000 square miles of most fertile land, and possibly cause a loss of more than ten million dollars from a large crevasse.

The chief weakness in this system of protection by levees and revetment lies in the ever-present danger that some new twist of deep current during a great flood will undercut some short piece a few feet in length in the more than 1,000 miles of river bank where there is no revetment; or that a stream of water will percolate somewhere beneath the high levee following a deep, hidden stratum of sand or gravel and burst up during the night in a "sand-boil," or that it may tear up the corner of an old revetment.

One or more crevasses through the best of these standard levees will be probable for many years to come in the high flood of each ten year period, with the further probability that once, in say fifty years, there will be a coincidence of large simultaneous floods on tributaries from widespread heavy rainfall, like that of a few months ago, which will result in the delivery of a flood carrying about as many cubic feet per second as that from which this region is now recovering.

The protection of levees against rupture from under-cutting by the deep current, which is most active at the concave shore of the bends, is by a revetment, most commonly by means of a "mattress" composed of willow trees and twigs interwoven with steel cables, 200 feet in width, more or less; and extending for a few thousand feet up and downstream along the threatened bank. This mattress is placed on the river bed below the low water level and held in place by loading with stones. This work of mattress building is extremely costly, at present averaging about $375.000 per mile of length. It necessarily proceeds slowly, both from the slow supply of funds, and from the limited supply of small willow trees, which are cut along the neighboring river banks and wooded islands.

The several construction plants have an aggregate capacity of fifteen or twenty miles per year, but from three to five miles per year is about all that the actual construction for the past ten or fifteen years has averaged, and out of a total shore line of more than 2.000 miles between St. Louis and New Orleans less than 140 miles has been effectively revetted.

The need of revetment obviously is greater near the water front of cities like New Orleans, Greenville, and so on, and particularly along the concave shore of the bends, but history shows that other parts of the shore are not wholly immune from danger. To protect the entire length of both banks of the main river only downstream from Cairo, at the recent rates of cost and progress, would cost upward of 500 million dollars, and take more than 200 years, and when once put down, revetment is not imperishable for all time, and in some rare cases the current has torn it up.

In the great flood of 1922, two serious crevasses occurred, one at Weecama on the west bank near the little town of Ferriday, the other on the east bank below New Orleans at Poydras, each of which I visited and carefully studied. . . . At the Ferriday (or Weecama) crevasse the land was flooded apparently from three feet to five feet in depth upstream, downstream and inland, as far as one could see. Only tree tops and the tops of houses were visible in a widespread scene of devastation. Conditions were much the same at the

Poydras crevasse, which occurred very near to the spot where the levee was cut in the present flood. At each of these crevasses at the time of my visit a current was tearing through with a volume nearly equal to that of the Niagara or St. Lawrence rivers. Until one has seen such a crevasse, imagination fails to tell what a terrible affair it is. You cannot visualize from the still pictures in the papers the mile-wide river swirling and dashing through a slight earth dam.

The Mississippi at high floods carries two million cubic feet of water per second, or ten times as much as the ordinary flow of the St. Lawrence. This gives some measure of the size of a spillway, natural or artificial, that would be necessary to produce any important effect in lowering the flood. The vast volume through the crevasse cuts to 100 or perhaps 150 feet in depth near its mid-channel for a distance of several hundred feet along its current, and apart from the damage to the farming property inundated, this leaves an awful gap to be filled up when the levee is restored after the flood has subsided. These possibilities of a breach of the levee by some new freak of the current in under-cutting the banks at a point where danger is not obvious have been mostly ignored in the recent discussions of what is necessary for safeguarding these reclaimed delta and swamp lands. After levees shall have been built everywhere from above St. Louis to below New Orleans to the full height and thickness prescribed by the Mississippi River Commission, one who dwells behind the levee on low ground should live always in view of the possibility of a break which may drive him out and drown his hogs and chickens, although it occurs forty miles upstream from where he lives. A break less than ten feet wide at the time of discovery may within a few hours spread to cut out more than 1,000 feet in length of levee and it is then beyond all possibility of restraint.

Picture a thin earth dam of very unstable material, built of whatever material can be scraped up close at hand, mostly river silt or damp mud, and 1,500 miles in length; for parts of its length resting upon a foundation of swamp mud at the

> side of old bayous or abandoned channels that may have left streaks of pervious gravel in their beds! . . .

The chief remedies advocated for the prevention of flood disasters along the lower Mississippi are:

(1) The increasing and strengthening of the existing levees.

(2) The construction of a system of large spillways or overflow channels along the lower valley, to carry off the excess water discharged during floods.

(3) The construction of a series of great reservoirs in the upper valley and along the chief tributaries, in which flood water could be impounded, and allowed to escape downstream at a safe rate.

At present there is no general agreement as to the best scheme to adopt. Serious objections have been advanced against each of the projects outlined above. The problem is, however, of the utmost importance; and engineers and geologists are making attempts to solve it.

Erosion and Soil Wastage

The problem of the erosion of tilled fields should be considered logically in connection with the matter of floods, because the two processes are connected. The subject is concisely treated in the following extract from an authoritative article (Bennett, 1928).

> Soil wastage by erosion is the most serious problem relating to land utilization in this country. It is the direct cause of the distressing financial condition of thousands of farmers struggling with lands enfeebled or worn out by rain-wash. Crop surpluses, with their depressing effect upon prices of farm products, come and go; but land impairment by erosion is a costly evil that stays. Indeed, it is a problem which with the prevailing absence of national concern about it, is growing steadily worse. It affects nearly all sloping areas over most of the uplands of the nation, and there is but little upland which is without slope. Even the areas that seem flat to the eye usually have sufficient slope for rain-water to flow off the fields and pastures. Wherever this happens there is some washing away of the soil. The removal is slower on the

PLATE V

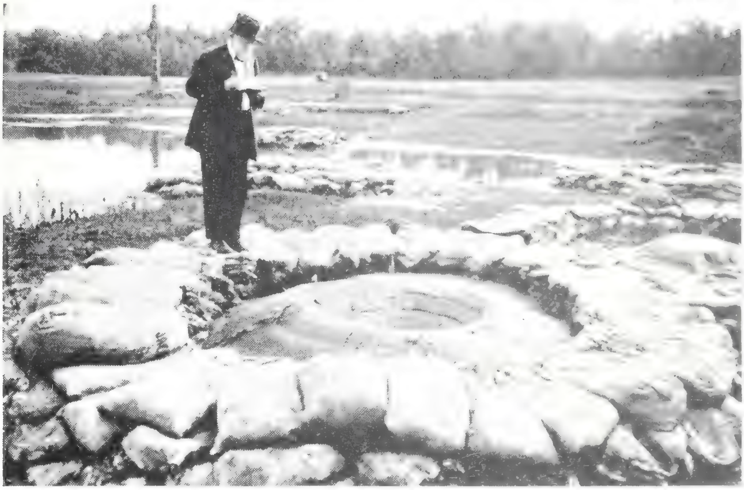
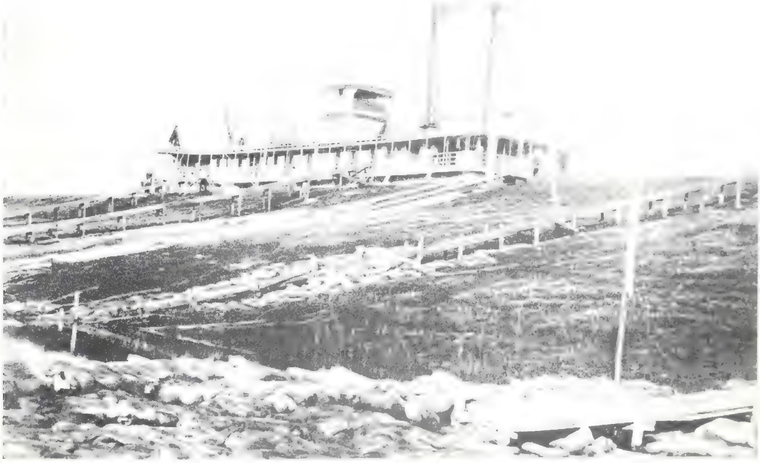


Photo John R. Freeman

A. A "SAND-BOIL" ON THE LOWER MISSISSIPPI

Formed by water from the flooded river working through a porous sand beneath a levee, and bursting up on the lowland beyond.



Mississippi River Commission

B. THE MISSISSIPPI IN FLOOD

In time of flood the level of the river rises above that of the surrounding land. A sandbagged levee is shown holding in the river, on which the steamboat is floating.

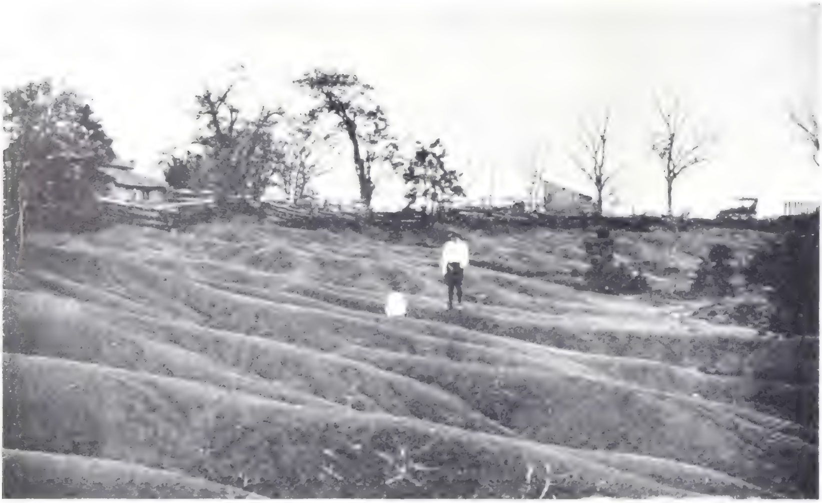


Photo Hugh H. Bennett

A. VALUELESS LAND

Rendered so by careless plowing.

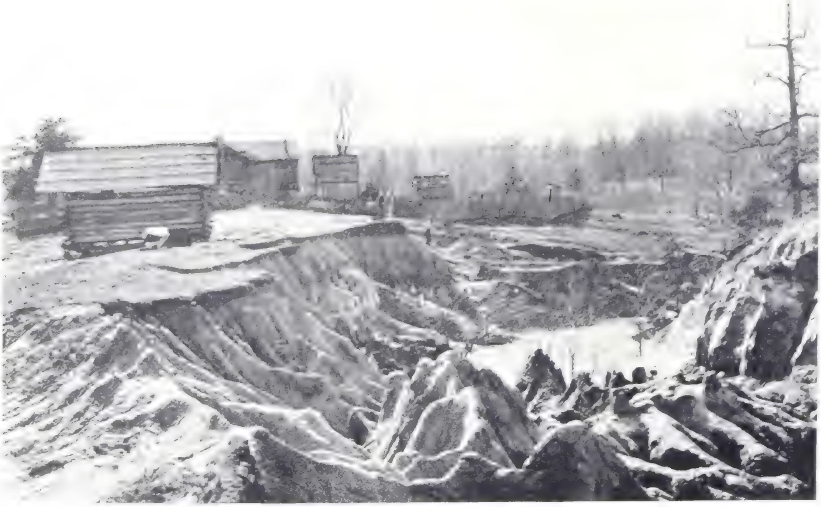


Photo W. R. Mattoon, U. S. Forest Service

B. A RECENT GULLY IN MISSISSIPPI

Gradually destroying agricultural land.

smoother lands, and the effect is less serious on some lands having peculiar resistance to the process. With increasing slope the transporting and eroding capacity of running water is greatly enlarged, since the load flowing water is capable of carrying, and also the abrasive effect, increases enormously with the velocity.

We sometimes hear farmers and even scientific agriculturists say, "Erosion is not a problem in our locality." In some places it is not a very serious problem, to be sure; but in many other localities where it is believed not to be operative at all, much damage is actually being done. In time the cumulative effect of soilwash becomes painfully apparent, as spots of unproductive clay and exposed bedrock and as fields from whose surface the entire soil has been stripped off. The hideous gullies that mar the landscape of so many localities represent the more advanced and spectacular work of erosion; and, although something in excess of thirteen million acres of formerly cultivated land in this country have been permanently ruined for farming purposes by gullying, this form of devastation constitutes but a small fraction of the wastage.

It is sheet erosion that is doing most damage to our farm lands and over-grazed pastures. By this process the surface of the ground is gradually planed down more or less equally at all points. Every heavy rain and even the showers of springtime strip from the cultivated land sheets of soil matter, and this from the surface, the richest part of the fields. If, after a fall of rain, one looks, one sees wherever there is cultivated and over-grazed land water flowing across the slopes and down the rills and brooks, not clear but discolored or turbid with soil material gathered from the countryside. This coloring matter represents so much soil and soil fertility gone for eternity, so far as the areas whence came the material are concerned.

Abnormal soil washing, with the helpful assistance of man, is doing more damage to the agricultural lands of the nation than all other processes, both natural and artificial combined.

. . . More than eight-tenths of the area of the United States is underlain by sedimentary deposits; that is, rocks and unconsolidated strata composed of material that was washed, largely or entirely, from older land areas, some of which have been completely effaced from the earth. These water-formed beds are thousands of feet in thickness. It is not uncommon to drill into them more than four thousand feet for oil. Through the eons of geological periods the rocks of ages have decayed to give the material of our soils, and from the very beginning rainwater impinging against these detrital products have torn them asunder and distributed them to the seas to form new land areas of coastal marsh and submerged continental shelfs. The gashes this instrument has cut are utterly beyond calculation. Some parts of the Blue Ridge Mountains of the Appalachian System have been hewn down through thirty thousand feet of decayed rock and eroded soil, or ten times their present height. . . .

Nevertheless, man has entered very actively upon the task of assisting nature with the work of land destruction. By cultivating unprotected and excessively steep slopes, hundreds of thousands of square miles have been brought to complete ruin throughout the world, and far greater areas have been seriously impaired by unrestrained rainwash. Solid rock and sterile, gullied slopes frown down from stripped uplands over vast areas of China and Asia Minor. Unwise treatment of sloping land by the farmers of the past has so restricted the area of China's arable land that hordes of highlanders have been driven into the valleys for sustenance, or forced to husband their remaining soil upon terraces built like scaffolds along the sides of hills and mountains. With the best possible utilization of the remaining soil, famines are continually recurring upon that disturbed part of the earth's surface. In some parts of the world wastage of fertility by erosion has caused the downfall of nations, and even the destruction of civilizations.

Youthful America is not guiltless of unwise use of the land upon a large scale. Steep slopes and land that washes much too readily have been used for crops without provision for checking rainwash; indeed, they often have been used in such manner as to encourage and accentuate the wastage. Even grazing lands have been sorely impoverished or destroyed in many parts of the west and in some parts of the east. . . .

. . . Down in the southern Piedmont, for example, where ninety thousand acres of formerly good farm land have been destroyed in a single county, serious-minded citizens speak vehemently of the shameful land practices of the farmers of one, two or three generations ago, not to mention some of those who, still operating, call themselves farmers instead of soil miners. The ninety thousand acres that stare them in the face, a grinning skeleton of land that could have been saved, is not a guess. The area was studied in detail by experienced soil scientists and its outlines carefully plotted on a government map. It was classed as gullied land having no further agricultural value, save for an occasional strip temporarily left between expanding gullies. Bedrock has been exposed in a thousand places. In brief, this area has been so completely devastated over most of its extent, it cannot be reclaimed to cultivation until centuries of rock decay have restored the soil, and it has only moderate value for tree growth.

Too few are concerned about land destruction of this nature, even when it is pointed out that this wasted Piedmont area is but one of a vast number of similarly eroded areas throughout the country, many equally bad and others worse. If a foreign army should invade this country and destroy ninety thousand acres of land, who doubts the nation would hasten to spend twenty billion dollars to redress the wrong? . . .

In the great region of loessial soils, the Brown Loam Belt that follows along the east side of the Mississippi River from Baton Rouge, Louisiana, northward across Mississippi, Tennessee, and southwestern Kentucky, and onward far up the Missouri and its tributaries, county after county includes ten, twenty, or thirty thousand acres which have been destroyed by gullying and sheet erosion. In some of the more southerly counties of this region agriculture has been largely driven out of the uplands, and many tracts of rich alluvial soil have been buried beneath a blanket of comparatively inert sand deposited by flood water. Stream channels have been choked with erosion-debris, and overflows have become so exceedingly common that large tracts of highly productive alluvium, formerly tilled, are now rated as swamp land having little value for any purpose. Some streams, formerly navigable, have been so choked with sand and mud they can no longer be plied by boats. . . .

In the black belt of central Texas, one of the greatest cotton-producing regions of the world, white areas representing the basal chalk and marl beds dot the landscape of the rolling sections. These are the product of erosion. They consist of non-arable land that has taken the place of some of the most productive cotton soil known anywhere. In one country 13.5 per cent of the entire land area was classed as eroded land whose productive value has been very seriously impaired or practically destroyed. . . .

The government soil experts who recently completed a land survey of a county in northeastern Kansas found that an average of at least six inches of soil had been removed from the uplands of the county, where the predominant soils are silt loams, highly productive types, as valuable for the growing of corn and wheat probably as any upland known to man.

Nearly all tilled slopes of this county were found to have suffered, some much more severely than others. In one part of this area that was examined by the writer in the fall of 1927, a tract of original timber was seen, which had from one to two feet of extraordinary rich silt loam soil overlying clay. This was so abundantly supplied with dark humus and so mellow and permeable it was easy to dig down with the bare hand to the depth of the subsoil. Outside the timber on the same degree of slope the same soil in most places had lost all the surface material down to the clay, and in many places six inches or more of the subsoil itself had washed away. Indeed, patches were found where both soil and subsoil had departed, leaving bedrock exposed. One valley was found by actual survey to have lost from eight to forty inches of soil over 86 per cent of its upland area since clearing forty years ago. In apple orchards on these wasted lands the trees were making no growth, or were dying, as the result of excessive loss of moisture on the sunbaked clay in times of drought.

Near the Kansas-Nebraska line an apple orchard was seen in the bottom of a beautiful valley where the trunks of the trees had been completely buried by silt washed down from the adjacent hillsides and ridge crests. The raised surface of the ground stood among the branches of the trees, five feet above the original level of the orchard. The owner said the trees had shown no evidence of damage by the deposition. "But the trees were doing nicely before this washed-in material was deposited about them; they needed no more soil. The soil is needed very badly up there on the thin slopes where it came from."

Close by this orchard a gully is advancing at a minimum rate of one hundred and fifty feet a year. This is seventy-five feet deep, three hundred feet wide in places and nearly three-fourths of a mile long. It is destined to destroy all the farm land in this fertile valley, and its diverging trenches undoubtedly will cut to pieces the adjacent highlands.

Many valleys in the youthful agricultural country along the Missouri and its tributaries have undergone the same or similar vicissitudes. As a result, fields, and in some instances entire farms, are being abandoned. Sheet erosion is gradually thinning down the gentler slopes far back from the river. In many places twelve or fifteen miles from the Missouri, numerous wheat and alfalfa fields seeded in the fall of 1927 were severely damaged during a single period of autumn rains. Each depression made by the seed drills was converted into a rillway or small gully, while the wheel tracks of the seeder rapidly grew into ugly ditches. Most of the young plants were washed out of the ground and forty tons of soil an acre were carried off the steeper slopes. The only instance observed in several Missouri and Kansas counties of this region where a farmer had done anything to check the wastage was that of a series of wheat-straw stacks placed in a depression at the base of converging slopes. One of these stacks had caught and held four hundred and thirty tons of soil which had been washed down from the near-by slopes during the rainy period referred to. That sort of thing, however, can scarcely be considered as a real effort at soil conservation; for the place to hold the soil is in the fields and not in the valleys after it has left the fields.

There are no soil-saving terraces in this region, as a rule. The farmers generally do not even know what they are. Practically nothing is being done to conserve the soil; whereas a very great deal is being done to hasten its loss, such as plowing corn rows up-and-down the slopes, thus forming gutter-like "middles" to serve as ditches for concentration and increased scouring effect of rainwater. Where the rows accidentally follow the contour it is a common practice in springtime to plow furrows down the slopes in order to lead the water out of the inter-row depressions. Almost invariably these furrows grow into deep gullies that divide, capture and render useless for cultivation field after field.

This neglect of the land to the unceasing impoverishing effects of erosion is the rule, not the exception, throughout the entire central and upper Mississippi Basin. It is not restricted to the Missouri River area by any means.

One might reasonably suppose that erosion is of negligible importance in the dry regions of the West. Such is not the case, for many localities, at least. Because of certain soil peculiarities, such as the common tendency for the soils of the drier regions to crack or crumble into a loose, fluffy condition on drying, erosion is exceedingly severe in many parts of the West, even in desert areas.

In the cattle country of west Texas and central New Mexico, numerous places were observed recently, where deep rich valley soil, representing the accumulation of ages, had been washed out largely or wholly, leaving behind an absolute waste. The washing that causes the destruction or extreme impairment of these valuable grazing lands usually has its beginning in those places where the vegetation has been removed and the ground surface broken, as in cattle trails and bedding grounds, roadways, diversion ditches and prairie-dog towns. In one valley area of the Davis Mountain region of west Texas a thousand acres of former good grazing land were found to have been almost completely destroyed as the result of washing started in a prairie-dog town, where the vegetation had been eaten and the ground punctured with holes. . . .

Recently a layer of infertile sandy material swept out from a burned-over hillside in the southwestern United States was deposited over an orange grove of great value. The trees quickly showed distressing injury, some of them dying. It became necessary to rake the infertile detritus back from the base of the trees, wherever the deposit was less than a foot thick, and to haul it out of the grove where it was deeper. It is said to have cost a hundred thousand dollars, or twelve hundred dollars per acre, to remedy the distressing situation, which was brought about as the result of a single rainy period. The grove cannot stand another such disaster, as the owners see it. And there will be many other farms in many other parts of the nation that will not be able to stand the cost if we do not do a great deal more than we have done in the past to check the evils of erosion. . . .

At Spur, in subhumid western Texas, experiments conducted for the purpose of determining the possibilities of storing moisture in the subsoil for summer crop use revealed the astounding fact that forty-one tons of soil matters were removed from one acre by one year's precipitation of twenty-seven inches, and this on ground of only 2 per cent slope. A slope no steeper than this is not far removed from level ground, so far as the eye is capable of detecting. Of the rainfall, ground covered with buffalo grass retained 84 per cent, while fallow ground retained only 55 per cent. As the result of terracing the fields, much of the rainfall was stored in the subsoil, and the yield of cotton was considerably increased as a result.

The highly valuable loessial or wind-deposited soils of the Mississippi Valley if neglected, melt away with rain, almost like sugar, forming broad and deep gullies that invade the countryside with far greater desolation than that wrought by shell fire, trench, or mine upon the fields of France. The combined extent of land destruction during the World War was small in comparison with the evil work that has been done by soil erosion in single localities in many parts of the United States. . . .

So long as rain falls upon the earth there is going to be soil erosion. The process is as natural as the process of decay in a fallen tree. However, we need not concern ourselves with that slow type of washing that takes place on forested lands, provided these are not overgrazed and repeatedly burned; nor need there be much worry about areas well covered with grass, such as that which matted the prairies and much of the eastern plains region in the central part of the United States about two generations ago, i.e., before these vast acres were broken to establish our wheat and corn belts. The evil part of erosion is that which, with the assistance of man and animals, exceeds the natural order of things by upsetting the normal equilibrium between the ground, on the one hand, and the vegetative cover and other stabilizing agencies, on the other hand. It is the excessive washing that has followed the removal of grass, trees, and bushes, and the cultivation of steep slopes and lands of excessive vulnerability to washing, without making provision for assisting the disturbed bare soil to hold itself in place that must be dealt with, if the wastage is to be checked. . . .

The erosional debris discharged into streams does not diminish their volume. The suspended matter, the dissolved matter and the drag material rolling down the beds of the rivers in waves like sand-dunes, most of which comes from tilled lands, abandoned fields and overgrazed pastures, adds to the volume of floodwater very considerably. This is an obvious mathematical truth.

A feature of utmost importance in this connection is the largely increased rate at which water flows off those areas that have had their absorptive mellow topsoil washed off down to impervious clay, rock or incompletely weathered subsoil material. This, coupled with the erosional-debris swept into stream channels, has been the cause of increased floods in many rivers, of increased swampiness over vast areas of bottom land and of excessive surface deposition of comparatively infertile sand, gravel and cobbles over productive alluvial plains and lower slopes.

Thus erosion works in the quadruple rôle of increasing the amount of sediments discharged into the streams; of reducing the agricultural value of the eroded uplands; of damaging or ruining alluvial bottoms by overwash and by increased swampiness; and of causing rainwater to flow off impervious washed areas much faster than formerly. This is a serious indictment of the process. But it is none too serious, and unless we do very much more in the future to check the evil scourge than we have done in the past, it can be said now, as previously stated, and without any fear of subsequent punishment for false prophecies, that this country is really but upon the threshold of disastrous soil erosion. This prediction is based upon the fact that subsoil material usually washes faster than surface-soil material and is always more difficult to conserve with the known implements of remedial measures.

What is needed most to conserve soil and soil fertility is a greatly increased use of hillside terraces as a means of slowing down erosion. In the general neglect of studies relating to the fundamentals of the problem, the best thing to do with some peculiar kinds of land has not yet been determined. It is not known, for example, what type of terraces is best suited to a considerable number of these peculiar soils, or, indeed, whether or not any kind of terrace will save some of them. But it is known that broad embankments, of the Mangum terrace type, are highly effective as conservers of both soil and soil moisture in many parts of the country. In the less steeply sloping fields these embankments can be cultivated over about as easily as any other part of the field. There will be, however, conditions of slope, soil and climate where other forms of embankments must be resorted to for effective results, and no doubt it will be necessary under some conditions to reënforce these with grass or vines or else to resort to expensive wall-terraces, such as have saved much land in the Mediterranean Basin and in Palestine for more than two thousand years.

Terraces are very practical things. They can be constructed with plows, scrapes, and drags at those times of the year when farm work is not pressing. They function much after the manner of hedge-rows and fences in catching and holding soil and moisture coming from slopes above. Being adjusted to slope and soil and having the form of an embankment, they are much more efficient, as a matter of course. They must be laid out correctly, however, or costly breaks will occur. Farmers can be taught how to do this by county agricultural agents, when the latter have been taught how to do it themselves, and that is what is being done in many parts of the South. . . .

There are many sloping fields, however, that cannot be protected by terraces. Some types of soil wash too readily for cultivation and should not be tilled under any circumstances. In the Appalachian Plateau fields are still being cleared where the farmers know that but from one to three crops can be grown before the soil washes away. . . .

Not a very cheerful picture of our American system of land usage has been painted in this article. With past performances as a background, there is exceedingly little upon which to build a glowing account of our stewardship of the land. However, with the recent soil-conservation activities in Texas, Oklahoma, and several other localities, there is good cause to look for a very large expansion in the practice of these commendable methods in the near future, especially if we perform our national and individual duties of helping the farmers.

BIBLIOGRAPHY

Chapter III—Streams and Valleys

Robert Bakewell, *An Introduction to Geology.* 3d American Ed., New Haven, 1839, p. 387.

Hugh Hammond Bennett, *The Wasting Heritage of the Nation.* Scientific Monthly, vol. 27, 1928, pp. 97-124.

William Buckland, *Reliquiæ diluvianæ.* American Journal of Science, vol. 8, 1824, pp. 150, 317.

W. M. Davis, *The Rivers and Valleys of Pennsylvania.* National Geographic Magazine, vol. 1, 1889, p. 200.

John R. Freeman, *Needed: More Science in Flood Control.* Technology Review, vol. 30, 1927, pp. 95-102.

G. K. Gilbert, *Report on the Geology of the Henry Mountains.* 2d Ed., U. S. Geographical and Geological Survey of the Rocky Mountain Region, Washington, 1880, pp. 117-118.

Edward Hitchcock, *Report on the Geology of Vermont.* 1861, p. 221.

Lawrence C. Johnson, *The Nita Crevasse.* Bulletin of the Geological Society of America, vol. 2, 1891, pp. 20-25.

Sir Charles Lyell, *Principles of Geology.* 9th Ed., New York: Appleton, 1860, pp. 255-256, 265-266, 267, 277.

Hugh D. Miser, *San Juan Canyon, Southeastern Utah.* U. S. Geological Survey, Water-supply Paper 538, 1924, p. 57.

John Playfair, *Illustrations of the Huttonian Theory of the Earth.* Edinburgh, 1802, pp. 102, 116, 124, 354.

J. W. Powell, *Physiographic Processes* (in *The Physiography of the United States*). National Geographic Society, New York: American Book Company, 1896, pp. 7-9.

The New Republic, *Can Floods be Prevented?* Editorial, The New Republic, New York, May 18, 1927.

Mark Twain, *Life on the Mississippi.* New York: Harper & Brothers, 1874, Chapter I, Chapter XVII.

CHAPTER IV

GLACIERS AND GLACIATION

Development of the Glacier Hypothesis

A HUNDRED years ago no one imagined that glaciers had ever been much more or much less extensive than the existing ones. Yet the presence of polished and striated rock surfaces, together with a mantle of heterogeneous stones, sand, and clay, over extensive areas far from living glaciers, was beginning at that time to arouse curiosity and to cause comment. In 1821 Benjamin Silliman (1821, p. 49), first professor of Geology at Yale, wrote:

> The almost universal existence of rolled pebbles, and boulders of rock, not only on the margin of the oceans, seas, lakes, and rivers; but their existence, often in enormous quantities, in situations quite removed from large waters; inland, in high banks, imbedded in strata, or scattered, occasionally, in profusion, on the face of almost every region, and sometimes on the tops and declivities of mountains, as well as in the valleys between them; their entire difference, in many cases, from the rocks in the country where they lie, rounded masses and pebbles of primitive rocks being deposited in secondary and alluvial regions, and vice versa—these and a multitude of similar facts have ever struck us as being among the most interesting of geological occurrences, and as being very inadequately accounted for by existing theories.

No known cause seemed adequate to account for so vast a phenomenon; catastrophe and cataclysm were appealed to. John Finch (1824, pp. 31-43) wrote:

> After the production of these regular strata (Tertiary) of sand, clay, and limestone, etc., came a terrible irruption of water from the north, or north-west, which in many places

> covered the preceding formations with diluvial gravel, and carried along with it those immense masses of granite, and the older rocks, which attest to the present day the destruction and ruin of a former world.

At the same period Silliman remarked that no one would object to ascribing most of these deposits to that "vindictive infliction", the deluge of Noah. He (Silliman, quoted by Gregory, 1918, pp. 133-134) goes on to say:

> We would beg leave to suggest the following as a cause which *may* have aided in deluging the earth, and which, were there occasion, *might* do it again.
>
> The existence of enormous caverns in the bowels of the earth (so often imagined by authors), appears to be no very extravagant assumption. It is true it cannot be proved, but in a sphere of eight thousand miles in diameter, it would appear in no way extraordinary, that many cavities might exist, which collectively, or even singly, might well contain much more than all our oceans, seas, and other superficial waters, none of which are probably more than a few miles in depth. If these cavities communicate in any manner with the oceans, and are (as if they exist at all, they probably are) filled with water, there exist, we conceive, agents very competent to expel the water of these cavities, and thus to deluge, at any time, the dry land.

Later the deposition of the drift was ascribed to the action of icebergs floating southward in a temporary sea. The true explanation was reached by Louis Agassiz, a Swiss scientist, who observed the glaciers in the Alps and compared their effects with the drift phenomena of northern Europe. He published first in Europe (1840) and later in America (1846) his revolutionary idea, that both continents had formerly been partly overspread by great ice sheets. This conception met with tremendous opposition and was not generally accepted until after 1860.

Thus thinking people gradually became accustomed to the idea that the present glaciers are mere shreds and remnants of their former selves. But still another surprise was in store, a surprise that did not appear until the twentieth century. It consisted in the discovery beneath the ice in both Arctic and Antarctic regions, of outcrops of coal beds and of rocks containing fossil leaves of warm-climate plants. No more conclusive proof could be asked that the Earth has at times enjoyed mild climates from pole to pole. And with the growth of our knowledge derived from the rocks, it has appeared that our present conditions are not normal, but are decidedly colder than usual. Students of climate and geologists agree that we are probably witnessing the closing stages of an ice age, the Pleistocene, that our present climates are remnants of a frigid episode, and that in time they will warm up to the level that characterized the Earth before the last refrigeration occurred.

During the nineteenth century, the theory was generally held that the Earth was formed in a molten state, and that it has been gradually cooling off ever since. After Agassiz had shown that a period of frigidity had recently affected the Earth, many hailed this as the beginning of the end toward which this sphere had been traveling since it first began to cool off. There was predicted an increased chilling and a final catastrophe in which life would be destroyed and the Earth itself would become as cold and as dead as the moon.

This gloomy prediction was overthrown by the gradual discovery of old glacial deposits solidified into rock and overlain by later rocks deposited under unmistakably mild conditions. This evidence shows conclusively that the Earth has been refrigerated at various times throughout its history, and that after each of these glacial periods the old mild climate has returned. And the conclusion has been reached that the most recent ice age was only a temporary affair from which indeed we seem to be emerging at present.

Mountaineering in the Alps

Various parts of the Alps were climbed for pleasure long before any serious study was made of the characteristics and habits of the glaciers that occupy the valleys. Each year thousands of tourists and others continue to visit the Alps, and not a few undertake glacier expeditions like the one (Tutton, 1927, pp. 77-78) described below:

Perhaps nothing in mountaineering experience can equal, or at any rate excel, the charm and delight of a glacier expedition, the crossing of a high glacier pass, for instance, led by a guide so experienced that we have no anxiety about our route. There is first the romantic early morning start, by starlight, with rücksack on back and ice-axe in hand, preceded by the guide with his rope coiled over his shoulder and a lantern, and followed by the porter to relieve one of the greater part of the weight of provisions and essentials, and to make the necessary third on the rope. Then as we make rapid progress up the valley in the cold frosty air comes gradually the dawn of day, and the lighting up of the mountains one after another, first with the grey tints of daybreak, then with the crimson glow of sunrise, as the direct rays of the rising orb strike their summits in turn, and eventually light up the whole of them with the wonderful "Alpengluh." Next comes the delightful exhilaration of the glacier air, probably the purest in the world, as we leave the stony moraine behind us and set foot on the crystal-piled crisp surface of the solid ice, the specially efficient Alpine nails of our climbing boots biting well with a pleasant crunching sound that gives us confidence in the sureness of our footing, although it may have been necessary for the guide to cut a few steps in the smooth solid ice where we get on to it, as the edge is so often somewhat steep and rounded. For in the early morning the surface of the glacier is usually carpeted with a mass of freshly-formed crystals, by the freezing during the night of the water left by the superficial irregular melting and pitting of the gravel- or dust-strewn ice by the hot sun of the previous day, forming a "pile" of no less exquisite beauty than utility.

Then follows in succession the roping together of the three or more members of the party, guide first and porter last, the passage by natural ice bridges, or the leaping of imposing icicle-hung crevasses, the wandering in and out among the fantastic "séracs" of pale-blue ice, and the marking by our footsteps in Indian file of a clear track over the upper snowfields of almost blinding whiteness, as we traverse and zig-zag our way to the pass. Here we find our glacier goggles of the utmost value, saving us from inflammation of the eyes next day; and also our lanoline tube is brought into requisition, to prevent sunburn. It is a truly remarkable experience to one who is making a first visit to the higher Alpine regions, to find exposed parts blistered by the direct and snow-reflected rays of the hot sun, unless one takes these drastic precautions, while the feet are deep in cold snow. However, we are now arriving, and experience the sudden apparition of the glorious view at the other side of the pass, which was probably entirely hidden as we were approaching our goal; and we stand at length on the summit of our pass, or more correctly, on the ridge-depression which constitutes the "Col," and feast our eyes on the great panorama which lies before and around us. Then we feel that we are justified in making ourselves comfortable on a friendly rock, or eminence of snow, and enhancing the pleasure of the great moment by enjoying the most delightful of *al frésco* déjeuners, out of the contents of the well-provided rücksacks.

Alpine Glaciers

Lyell (1860, 222-223) opens his discussion of Alpine glaciers in this manner:

> *Glaciers.*—In the temperate zone, the snow lies for months in winter on the summit of every high mountain, while in the arctic regions, a long summer's day of half a year's duration is insufficient to melt the snow, even on land just raised above the level of the sea. It is therefore not surprising, since the atmosphere becomes colder in proportion as we ascend in it, that there should be heights, even in tropical countries, where the snow never melts. The lowest limit to which the perpetual snow extends downwards, from the tops of mountains at the equator, is an elevation of not less than 16,000 feet above the sea; while in the Swiss Alps, in lat. 46° N. it reaches as low as 8,500 feet above the same level, the loftier peaks of the

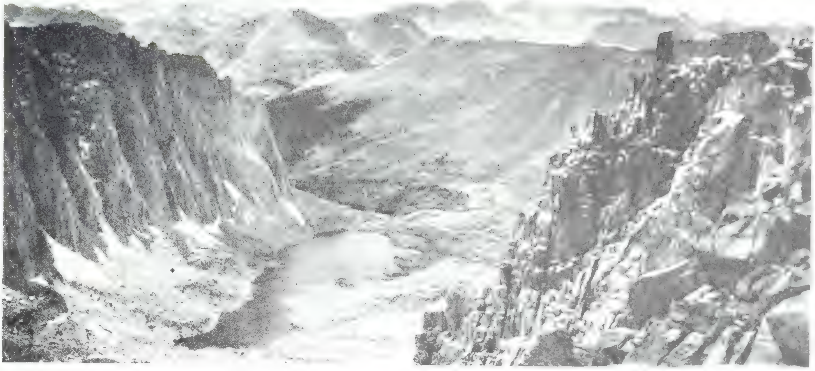


Photo Adolph Knopf

A. A GLACIATED TROUGH IN THE SIERRA NEVADA

Looking west from near Mt. Whitney, California.

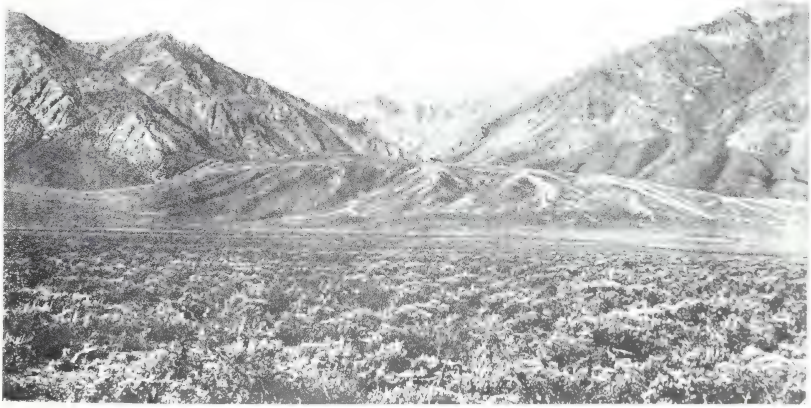
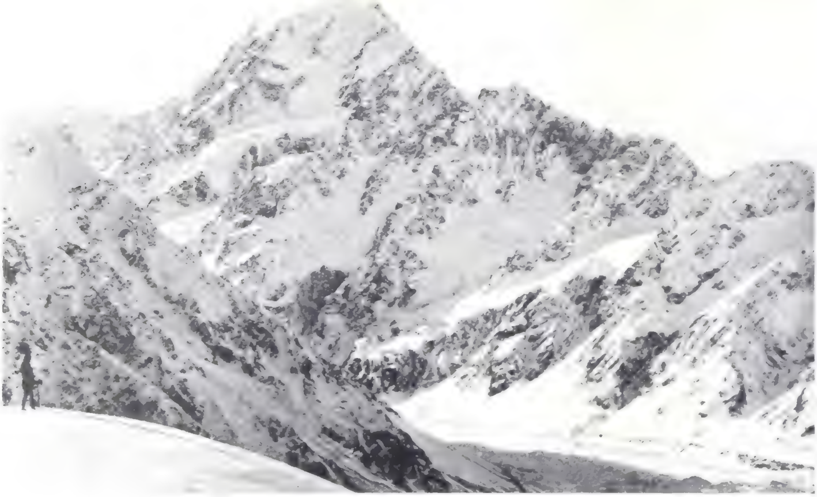


Photo François Matthes

B. TERMINAL MORAINE OF A VALLEY GLACIER

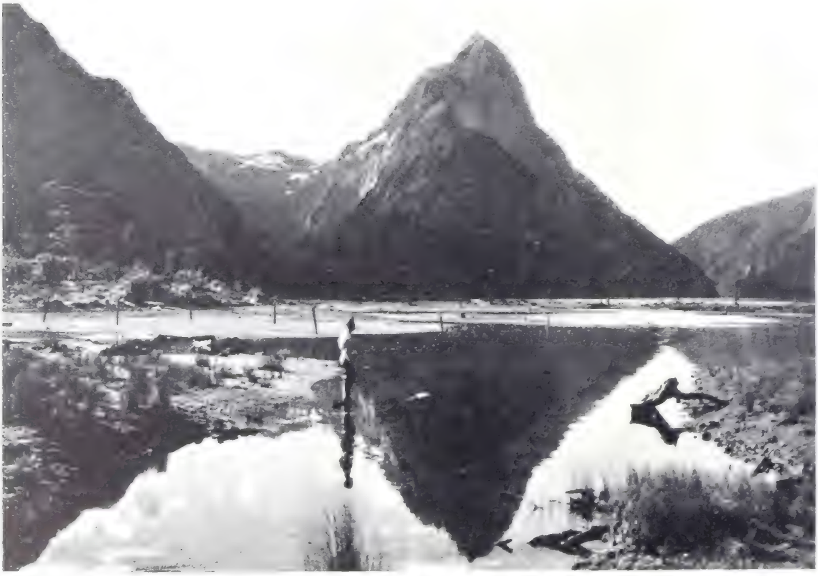
And the valley down which the ice advanced. Owens River country, California.



New Zealand Government Publicity Photo

A. NEAR THE HEAD OF A GLACIER-OCCUPIED VALLEY

Mt. Cook and Hooker Glacier, in the Southern Alps of New Zealand.



New Zealand Government Publicity Photo

B. VALLEYS THAT HAVE BEEN GLACIATED

Milford Sound, South Island, New Zealand.

Alpine chain being from 12,000 to 15,000 feet high. The frozen mass augmenting from year to year would add indefinitely to the altitude of Alpine summits, were it not relieved by its descent through the larger and deeper valleys to regions far below the general snow-line. To these it slowly finds its way in the form of rivers of ice, called glaciers, the consolidation of which is produced by pressure, and by the congelation of water infiltered into the porous mass, which is always undergoing partial liquefaction, and receiving in summer occasional showers of rain on its surface. In a day of hot sunshine, or mild rain, innumerable rills of pure and sparkling water run in icy channels along the surface of the glaciers, which in the night shrink, and come to nothing. They are often precipitated in bold cascades into deep fissures in the ice, and contribute together with springs to form torrents, which flow in tunnels at the bottom of the glaciers for many a league, and at length issue at their extremities, from beneath beautiful caverns or arches. The waters of these streams are always densely charged with the finest mud, produced by the grinding of rock and sand under the weight of the moving mass.

The length of the Swiss glaciers is sometimes twenty miles, their width in the middle portion, where they are broadest, occasionally two or three miles; their depth or thickness sometimes more than 600 feet. When they descend steep slopes, and precipices, or are forced through narrow gorges, the ice is broken up, and assumes the most fantastic and picturesque forms, with lofty peaks and pinnacles, projecting above the general level. These snow-white masses are often relieved by a dark background of pines, as in the valley of Chamouni; and are not only surrounded with abundance of the wild rhododendron in full flower, but encroach still lower into the region of cultivation, and trespass on fields where the tobacco-plant is flourishing by the side of the peasant's hut.

The glaciers of the Alps are not at present moving rapidly; the more sudden changes they effect occur in connection with the overflow of small lakes along some of the glacier margins. These lakes are discussed in the two extracts below (Tutton, 1927, pp. 130-131, 239-240):

> The most interesting case, however, of a glacier-barred lake is that of the Märjelen See, the beautiful bluish-green lake enclosed on the left (eastern) bank of the Great Aletsch Glacier, just beneath the Eggishorn. In this case it is not a moraine which dams it up, but the pure ice cliffs of the glacier itself, and not at the snout, but almost at exactly halfway in the course of the glacier. The ice-cliffs are constantly breaking off and floating on the lake as icebergs. . . . From time to time this lake used catastrophically to discharge itself without warning down the glacier, causing great damage to the villages below the snout of the glacier. Professor Tyndall had a chalet at Belalp, high above the snout end of the glacier, and while in residence there in the summer of 1872, a sound like the roar of a cataract was heard, just as he reached the chalet from an expedition up the glacier; a few minutes later, at a point on the Eggishorn side of the glacier, about midway between it and the Rieder Furka (opposite Belalp), a torrent broke through, which became a river sixty yards wide, dashing down the ravine between the glacier and mountain side, forming great waterfalls from the ice hummocks from time to time, sending spray high up into the air, and carrying down great blocks of ice with it. The torrent and ice avalanche eventually found its way down the valley of the Massa, doing great damage to crops and chalets on the way, and eventually reached the Rhone valley, where the diligence driver suddenly found his coach and six horses in three feet of water on the main road, while the Rhone itself became greatly swollen, until at length the cataract ceased with the emptying of the Märjelen See.
>
> The Swiss engineers have since made arrangements for the periodic automatic tapping of the lake, to prevent such disasters in the future.

It was this same little Glacier de Tête-Rousse which was responsible for a terrible disaster in the year 1892, when curiously enough the author stayed about three weeks afterwards at the Pavillon de Bellevue, on his first making the Tour of Mont Blanc. Owing to the formation of a lake or huge pocket of imprisoned water on the glacier, at a spot about ten thousand feet above the sea, and its sudden disruption, about half-past one in the early morning of July 12th, an immense freshet or avalanche of mixed water, ice, snow, and rock burst out down the mountain side, here known as the Desert de Pierre Ronde, and down the valley of the Bon Nant, the stream from the Glaciers de Bionnassay and Tête-Rousse, collecting on its way an immense amount of rock debris and stones, many thousands of tons in weight. This torrential avalanche rushed with an awful roar past and only just below the little village of Bionnassay, which was only perched up on the hillside by a few feet high enough to escape, and tore down to the junction of this side valley with the main Montjoie Valley, along which runs the road from St. Gervais to Contaimines, and overwhelmed more than half of the village of Bionay at the confluence; it then continued its mad rush down the main stream, the Bon Nant de Montjoie, tore up numerous trees by the roots, swept away all chalets by the riverside, destroyed a picturesque old bridge near St. Gervais called the Pont du Diable, and finally hurled itself against the solid structure of the Baths establishment at St. Gervais-les-Bains, which it battered to pieces, and carried away the debris, with its own rocks, ice blocks, snow, water, trees and mud, on to the open flats of the valley of the Arve on the other side of the road to Chamonix.

So sudden was the catastrophe, and in the middle of the night, that the loss of life was very great, about a hundred and fifty persons being killed or drowned, and a great number of others rendered homeless, besides the immense loss of property and the destruction of roads and bridges.

In three weeks afterwards the author saw the ruin; the whole valley of the Bionnassay was covered with brown mud to a depth in places of forty feet, and the author came across a levelled chalet by which an old woman was sitting, in hopeless despair, who said that she was the only survivor of her family of six people. The Contaimines road was a terrible scene of destruction, the marks of the torrent being visible five or six feet high on the roadside; and the Baths of St. Gervais were a hideous wreck and covered with slime and mud. Le Fayet was a scene of desolation, and the whole of the open valley around was a mass of stones, tree trunks, and the same brownish mud. Such was the fearful disaster of St. Gervais. There was an immense hole left in the ice of the Tête-Rousse Glacier from which the water had escaped, elliptical in shape and very much like a prodigious giant moulin or giant's cauldron.

The Baths of St. Gervais have been rebuilt on a safer site, and the French engineers have bored a tunnel in the Glacier of the Tête-Rousse, so that any sub-glacial water now finds its way out automatically, and it is almost impossible for a similar thing to happen again.

One of the first problems that confronted the early glaciologists was the question of how glaciers move. The Swiss Professor Hugi built a hut in 1827 on the Unteraar Glacier. The hut was carried along by the moving glacier, and Hugi was able to measure its rate. Fourteen years later, Agassiz found it in a position 4,712 feet from its initial position. In this same year, 1841, Agassiz bored six ten-foot holes in a row across the glacier, and fitted long stakes into them. A year later he returned and accurately measured the movement each stake had undergone. Those in the middle of the glacier had moved farther than the sides, and thus a fact familiar to modern students was first proved. Another worker, Professor Forbes, made a similar measurement on the Mer de Glace.

Lyell (1860, pp. 223-226) later summed up the work on glacier motion as follows:

The cause of glacier motion has of late been a subject of careful investigation and much keen controversy. Although a question of physics, rather than of geology, it is too interesting to allow me to pass it by without some brief mention. De Saussure, whose travels in the Alps are full of original observations, as well as sound and comprehensive general views, conceived that the weight of the ice might be sufficient to urge it down the slope of the valley, if the sliding motion were aided by the water flowing at the bottom. For this "gravitation theory" Charpentier, followed by Agassiz, substituted the hypothesis of dilatation. The most solid ice is always permeable to water, and penetrated by innumerable fissures and capillary tubes, often extremely minute. These tubes imbibe the aqueous fluid during the day, which freezes, it is said, in the cold of the night, and expands while in the act of congelation. The distension of the whole mass exerts an immense force, tending to propel the glacier in the direction of least resistance—"in other words, down the valley." This theory was opposed by Mr. Hopkins on mathematical and mechanical grounds, in several able papers. Among other objections, he pointed out that the friction of so enormous a body as a glacier on its bed is so great, that the vertical direction would always be that of least resistance, and if a considerable distension of the mass should take place, by the action of freezing, it would tend to increase its thickness, rather than accelerate its downward progress. He also contended (and his arguments were illustrated by many ingenious experiments), that a glacier can move along an extremely slight slope, solely by the influence of gravitation, owing to the constant dissolution of ice in contact with the rocky bottom, and the number of separate fragments into which the glacier is divided by fissures, so that freedom of motion is imparted to its several parts somewhat resembling that of an imperfect fluid. To this view Professor James Forbes objected, that gravitation would not supply an adequate cause for the sliding of solid ice down slopes having an inclination of no more than four or five degrees, still less would it explain how the glacier advances where the channel expands and contracts. The Mer de Glace in Chamouni, for example, after being 2,000 yards wide, passes through a strait only 900 yards in width. Such a gorge, it is contended, would be choked up by the advance of any solid mass, even if it be broken up into numerous fragments. The same acute observer remarked, that water in the fissures and pores of glaciers cannot, and does not part with its latent heat, so as to freeze every night to a great depth, or far in the interior of the mass. Had the dilatation theory been true, the chief motion of the glacier would have occurred about sunset, when the freezing of the water must be greatest, and it had, in fact, been at first assumed by those who favored that hypothesis, that the mass moved faster at the sides, where the melting of ice was promoted by the sun's heat, reflected from boundary precipices.

Agassiz appears to have been the first to commence, in 1841, aided by a skilful engineer, M. Escher de la Linth, a series of exact measurements to ascertain the laws of glacier motion, and he soon discovered, contrary to his preconceived notions, that the stream of ice moved more slowly at the sides than at the center, and faster in the middle region of the glacier than at its extremity. Professor James Forbes, who had joined Mr. Agassiz during his earlier investigations in the Alps, undertook himself an independent series of experiments, which he followed up with great perseverance, to determine the laws of glacier motion. These he found to agree very closely with the laws governing the course of rivers, their progress being greater in the center than at the sides, and more rapid at the surface than at the bottom. This fact was verified by carefully fixing a great number of marks in the ice, arranged in a straight line, which gradually assumed a beautiful curve, the middle part pointing down the glacier, and showing a velocity there, double or treble that of the lateral parts. He ascertained that the rate of advance by night was nearly the same as by day, and that even the hourly march of the icy stream could be detected, although the progress might not amount to more than six or seven inches in twelve hours. By the incessant though invisible advance of the marks placed on the ice, "time," says Mr. Forbes, "was marked out as by a shadow on a dial, and the unequivocal evidence which I obtained, that even while walking on a glacier we are, day by day, and hour by hour, imperceptibly carried on by the resistless flow of the icy stream, filled me with admiration." (*Travels in the Alps*, p. 133). In order to explain this remarkable regularity of motion, and its obedience to laws so strictly analogous to those of fluids, the same writer proposed the theory that the ice, instead of being solid and compact, is a viscous or plastic body, capable of yielding to great pressure, and the more so in proportion as its temperature is higher, and as it approaches more nearly to the melting point. He endeavors to show that this hypothesis will account for many complicated phenomena, especially for a ribboned or veined structure which is everywhere observable in the ice, and might be produced by lines of discontinuity, arising from the different rates at which the various portions of the semi-rigid glacier advance and pass each other. Many examples are adduced to prove that a glacier can model itself to the form of the ground over which it is forced, exactly as would happen if it possessed a certain ductility, and this power of yielding under intense pressure is shown not to be irreconcilable with the idea of the ice being sufficiently compact to break into fragments, when the strain upon its parts is excessive; as where the glacier turns a sharp angle, or descends upon a rapid or convex slope. The increased velocity in summer is attributed partly to the greater plasticity of the ice, when not exposed to intense cold, and partly to the hydrostatic pressure of the water in the capillary tubes, which imbibe more of this liquid in the hot season.

On the assumption of the ice being a rigid mass, Mr. Hopkins attributed the more rapid motions in the center to the unequal rate at which the broad stripes of ice, intervening between longitudinal fissures, advance; but besides that there are parts of the glacier where no such fissures exist, such a mode of progression, says Mr. Forbes, would cause the borders of large transverse rents or "crevasses," to be jagged like a saw, instead of being perfectly even and straight-edged. An experiment recently made by Mr. Christie, secretary to the Royal Society, appears to demonstrate that ice, under great pressure, possesses a sufficient degree of moulding and self-adapting power to allow it to be acted upon, as if it were a pasty substance. A hollow shell of iron an inch and a half thick, the interior being ten inches in diameter, was filled with water, in the course of a severe winter, and exposed to the frost, with the fuze-hole uppermost. A portion of the water expanded in freezing, so as to protrude a cylinder of ice from the fuze-hole; and this cylinder continued to grow inch by inch in proportion as the central nucleus of water froze. As we cannot doubt that an outer shell of ice is first formed, and then another within, the continued rise of the column through the fuze-hole must proceed from the squeezing of successive shells of ice concentrically formed, through the narrow orifice; and yet the protruded cylinder consisted of entire, and not fragmentary ice.

The agency of glaciers in producing permanent geological changes consists partly in their power of transporting gravel, sand, and huge stones to great distances, and partly in the smoothing, polishing, and scoring of their rocky channels, and the boundary walls of the valleys through which they pass. At the foot of every steep cliff or precipice in high Alpine regions, a talus is seen of rocky fragments detached by the alternate action of frost and thaw. If these loose masses, instead of accumulating on a stationary base, happen to fall upon a glacier, they will move along with it, and, in place of a single heap, they will form in the course of years a long stream of blocks. If a glacier be 20 miles long and its annual progression about 500 feet, it will require about two centuries for a block thus lodged upon its surface to travel down from the higher to the lower regions, or to the extremity of the icy mass. This terminal point remains usually unchanged from year to year, although every part of the ice is in motion, because the liquefaction by heat is just sufficient to balance the onward movement of the glacier, which may be compared to an endless file of soldiers, pouring into a breach, and shot down as fast as they advance.

The "staking" of glaciers in order to determine their rate of movement was carried on by various energetic men who were following the lead of Agassiz. John Tyndall, an inveterate climber, is the author (Tyndall, 1897, pp. 243-247) of this account.

Let me record here my experience of the Morteratsch glacier. I took with me in 1864 a theodolite to Pontresina, and while there had to congratulate myself on the invaluable aid of my friend Mr. Hirst, who in 1857 did such good service upon the Mer de Glace and its tributaries. We set out three lines across the Morteratsch glacier, one of which crossed the ice-stream near the well-known hut of the painter Georgei, while the two others were staked out, the one above the hut and the other below it. Calling the highest line A, the line which crossed the glacier at the hut B, and the lowest line C, the following are the mean hourly motions of the three lines, deduced from observations which extended over several days. On each line eleven stakes were fixed, which are designated by the figures 1, 2, 3, etc. in the Tables.

Morteratsch Glacier, Line A.

No. of Stake.	Hourly Motion.
1	0.35 inch.
2	0.49 "
3	0.53 "
4	0.54 "
5	0.56 "
6	0.54 "
7	0.52 "
8	0.49 "
9	0.40 "
10	0.29 "
11	0.20 "

As in all other measurements of this kind, the retarding influence of the sides of the glacier is manifest; the centre moves with the greatest velocity.

Morteratsch Glacier, Line B.

No. of Stake.	Hourly Motion.
1	0.05 inch.
2	0.14 "
3	0.24 "
4	0.32 "
5	0.41 "
6	0.44 "
7	0.44 "
8	0.45 "
9	0.43 "
10	0.44 "
11	0.44 "

The first stake of this line was quite close to the edge of the glacier, and the ice was thin at the place, hence its slow motion. Crevasses prevented us from carrying the line sufficiently far across to render the retardation of the further side of the glacier fully evident.

Morteratsch Glacier, Line C.

No. of Stake.	Hourly Motion.
1	0.05 inch.
2	0.09 "
3	0.18 "
4	0.20 "
5	0.25 "
6	0.27 "
7	0.27 "
8	0.30 "
9	0.21 "
10	0.20 "
11	0.16 "

Comparing the three lines together, it will be observed that the velocity diminishes as we descend the glacier. In 100 hours the maximum motion of the three lines respectively is as follows:

Maximum Motion in 100 Hours

Line A	56 inches
" B	45 "
" C	30 "

This deportment explains an appearance which must strike every observer who looks upon the Morteratsch from the Piz Languard, or from the new Bernina Road. A medial moraine runs along the glacier, commencing as a narrow streak, but towards the end the moraine extending in width, until finally it quite covers the terminal portion of the glacier. The cause of this is revealed by the foregoing measurements, which prove that a stone on the moraine where it is crossed by the line A approaches a second stone on the moraine where it is crossed by the line C with a velocity of twenty-six inches per one hundred hours. The moraine is in a state of longitudinal compression. Its materials are more and more squeezed together, and they must consequently move laterally and render the moraine at the terminal portion of the glacier wider than above.

The motion of the Morteratsch glacier, then, diminishes as we descend. The maximum motion of the third line is thirty inches in one hundred hours, or seven inches a day—a very slow motion; and had we run a line nearer to the end of the glacier, the motion would have been slower still. At the end itself it is nearly insensible. Now I submit that this is not the place to seek for the scooping power of a glacier. The opinion appears to be prevalent that it is the snout of a glacier that must act the part of ploughshare; and it is certainly an erroneous opinion. The scooping power will exert itself most where the weight, and consequently (other things being equal) the motion, is greatest. A glacier's snout often *rests upon* matter which has been scooped from the glacier's bed higher up. I therefore do not think that the inspection of what the end of a glacier does or does not accomplish can decide this question.

The snout of a glacier is potent to remove anything against which it can fairly abut; and this power, notwithstanding the slowness of the motion, manifests itself at the end of the Morteratsch glacier. A hillock, bearing pine-trees, was in front of the glacier when Mr. Hirst and myself inspected its end; and this hillock is being bodily removed by the thrust of the ice. Several of the trees are overturned; and in a few years, if the glacier continues its reputed advance, the mound will certainly be ploughed away.

The movement of glaciers is illustrated in other ways rather more gruesome than pleasant. In 1820 three guides in the service of a party of scientists were lost in an ascent of Mont Blanc. They started a snow-slide by their own weight, and were swept into a deep crevasse and buried by an avalanche of ice debris. In 1858, after studying the rate of motion of the glacier involved, Professor Forbes estimated that the bodies should appear about 1860, at the snout of the Glacier des Bossons. In 1861 their heads were discovered in a crevasse near the end of the glacier, almost at the time and place predicted by Forbes. The other parts of their bodies, well preserved, with their clothing and equipment, appeared successively during the four subsequent years. They had traveled in all nearly two miles.

In 1866 a Captain Arkwright was killed by a similar avalanche on the Ancient Passage (Mont Blanc). Thirty-one years later, in 1897, his body was delivered up by the Glacier des Bossons above Chamonix, where it was awaited by the unfortunate victim's mother and sisters.

In another place Tyndall (1897, pp. 75-79) describes the Grimsel and the Eggishorn:

This Grimsel is a weird region—a monument carved with hieroglyphics more ancient and more grand than those of Nineveh or the Nile. It is a world disinterred by the sun from a sepulchre of ice. All around are evidences of the existence and the might of the glaciers which once held possession of the place. All around the rocks are carved, and fluted, and polished, and scored. Here and there angular pieces of quartz, held fast by the ice, inserted their edges into the rocks and scratched them like diamonds, the scratches varying in depth and width according to the magnitude of the cutting stone. Larger masses, held similarly captive, scooped longitudinal depressions in the rocks over which they passed, while in many cases the polishing must have been effected by the ice itself. A raindrop will wear a stone away; much more would an ice surface, squeezed into perfect contact by enormous pressure, rub away the asperities of the rocks over which for ages it was forced to slide. The rocks thus polished by the ice itself are so exceedingly smooth and slippery that it is impossible to stand on them where their inclination is at all considerable. But what a world it must have been when the valleys were thus filled! We can restore the state of things in thought, and in doing so we submerge many a mass which now lifts its pinnacle skyward. Switzerland in those days could not be so grand as it is now. Pour ice into those valleys till they are filled, and you eliminate those contrasts of height and depth on which the grandeur of Alpine scenery depends. Instead of skyey pinnacles and deep-cut gorges we should have an icy sea dotted with dreary islands formed by the highest mountain-tops.

In the afternoon I strolled up to the Siedelhorn. As I stood upon the broken summit of the mountain the air was without a cloud; and the sunbeams fell directly against the crown and slopes of the Galenstock at the base of which lay the glacier of the Rhone. The level sea of *névé* above the great ice-cascade, the fall itself, and the terminal glacier below the fall were all apparently at hand. At the base of the fall the ice undergoes an extraordinary transformation; it reaches this place more or less amorphous, it quits it most beautifully laminated, the change being due to the pressure endured at the bottom of the fall. The wrinkling of the glacier here was quite visible, the dwindling of the wrinkles into bands, and the subdivision of these bands into lines which mark the edges of the laminæ of which the glacier at this place is made up. Beyond, amid the mountains at the opposite side of the Rhone valley, lay the Gries glacier, half its snow in shadow, and half illuminated by the sinking sun. Round farther to the right were the Monte Leone and other grand masses, the grandest here being the Mischabel with its crowd of snowy cones. Jumping a gap in the mountains, we hit the stupendous cone of the Weisshorn, which slopes to meet the inclines of the Mischabel, and in the wedge of space carved out between the two the Matterhorn lifts its terrible head.

Wheeling farther in the same direction, we at length strike the mighty spurs of the Finsteraarhorn, between two of which lies the Oberaar glacier. Here is no turmoil of crevasses, no fantastic ice-pinnacles, nothing to indicate the operation of those tremendous forces by which a glacier sometimes rends its own breast. The grimmest giant of the Oberland closes the view at the head of the Lauteraar glacier—the Schreckhorn, whose cliffs on this side no mountaineer will ever scale. Between the Schreckhorn and Finsteraarhorn a curious group of peaks encircle a flat snow-field, from which the sunbeams are flung in blazing lines. Immediately below is the Unteraar glacier, with a long black streak upon its back, bent hither and thither, like a serpent wriggling down the valley. Beyond it and flanking it is a ridge of mountains with a crest of vertical rock, hacked into indentations which suggest a resemblance to a cock's comb. To the very root of the comb the mountains have been planed by the ancient ice.

A scene of unspeakable desolation it must have been when not Switzerland alone, but all Europe, was thus encased in frozen armour—when a glacier from Ben Nevis dammed the mouth of Glenroy, and Llanberis and Borrodale were ploughed by frozen shares sent down by Snowdon and Scawfell—when from the Reeks of Magillicuddy came the navigators which dug out space for the Killarney lakes, and carved through the mountains the Gap of Dunloe. Evening came, and I moved downwards, over heaped boulders and tufted alp; down with headlong speed over the rounded rocks of the Grimsel, making long springs at intervals, over the polished inclines, and reaching the hospice as the bell rings its inmates to their evening meal.

On Saturday I ascended from Viesch to the Hotel Jungfrau on the slope of the Æggischhorn, and in the evening walked up to the summit of the mountain alone. As usual, I wandered unconsciously from the beaten track, getting into a chaos of crags which had been shaken from the heights. My ascent was quick, and I soon found myself upon the crest of broken rocks which caps the mountain. The peak and those adjacent, which are similarly shattered, exhibit a striking picture of the ruin which nature inflicts upon her own creations. She buildeth up and taketh down. She lifts the mountains by her subterranean energies, and then blasts them by her lightnings and her frost. Thus grandly she rushes along the "grooves of change" to her unattainable repose. Is it unattainable? The incessant tendency of material forces is toward final equilibrium; and if the quantity of this tendency be finite, a time of repose must come at last. If one portion of the universe be hotter than another, a flux instantly sets in to equalise the temperatures; while winds blow and rivers roll in search of a stable equilibrium. Matter longs for rest. When is this longing to be fully satisfied? If satisfied, what then? Rest is not perfection; it is death. Life is only compatible with mutation; when equilibrium sets in life ceases, and the world thenceforward is locked in everlasting sleep.

Glaciers as Agents of Erosion

During the last quarter of the nineteenth century and the first decade of the twentieth, a hot debate centered about the question, Are glaciers more powerful eroding agents than streams, or do they have a protective effect upon the floors on which they rest? Proponents of the latter view held that tributary valleys in glaciated regions were left hanging because they were occupied by protective glaciers, while the main valleys were free from ice and were deeply trenched by streams. Our modern belief that glaciers erode their valleys profoundly has never been more clearly stated nor more effectively argued than by W. M. Davis. The essential part of his argument (Davis, 1906, pp. 76-89) is quoted here.

> *The Present Condition of the Problem of Glacial Erosion.*—The problem of glacial erosion in mountains has in recent years been carried many steps towards its solution by means of a series of studies in which the forms of formerly glaciated and of never glaciated mountains have been systematically compared. It has thus come to be believed by a number of observers that the glacial erosion of piedmont lake basins must be extended to the over-deepening of the main mountain valleys far upstream from the lakes, and that the retrogressive glacial erosion of cirques carries with it the sapping and sharpening of the culminating ridges and peaks. The last-named effect is truly not the direct work of ice, but it is so closely dependent upon glacial erosion that it should be included in any discussion of the sculpture of mountains by glacial agencies, just as the wearing of slopes and ridges by the weather goes with the erosion of valley bottoms by rivers.
>
> The observations and discussions that have led to a belief in strong glacial erosion are to be found in many different essays. Some of the earlier essays were based on almost intuitive insight; as when Ramsay was led to advocate the glacial erosion of lake basins, Gastaldi to accept the glacial erosion of cirques, and Helland to announce the glacial erosion of fiords. Many of the later essays are more surely founded on comparative studies, such as those on over-deepened valleys in the Cascade mountains of Washington by Gannett, and in the Alps by Penck; on the fiords of Alaska by Gilbert, and of New Zealand by Andrews; on the cirques of the Sierra Nevada of California by Johnson, of the Carpathians by de Martonne, and of the Big Horns by Matthes; and of the sharpened peaks of the Alps by Richter, and of Skye by Harker. There has thus been a great growth in the number of facts to be explained and a notable advance in the methods by which ex-

planation is reached. It seems no exaggeration to say, in view of all this progress, that the sculpture of mountains by glaciers has been given that degree of extreme probability which we may fairly call demonstration. It should not, however, be overlooked that certain investigators still remain unconvinced, notably Heim and Kilian in the Alps, Bonney and Garwood in England, and Spencer and Fairchild in the United States.

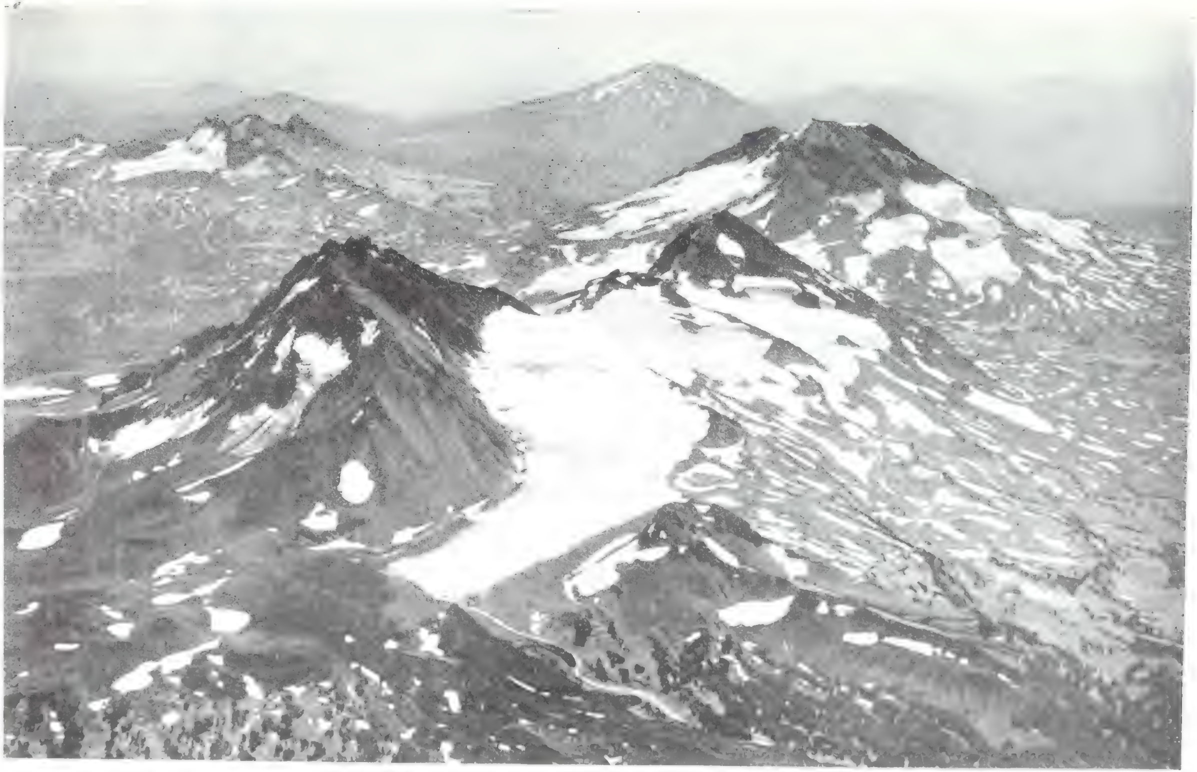
Method of Discussion here Adopted.—Most of those above named as believing in strong glacial erosion have not been led to their belief by an intimate study of the physics of glaciers or of the mechanics of glacial erosion, but by a study of the unlike forms that characterize glaciated and non-glaciated mountains, as has already been stated. Their line of thought seems to be essentially as follows: "It is difficult to determine whether the ancient glaciers did or did not significantly modify the mountains that they occupied, as long as we study only the structure and movement of existing glaciers. Let us therefore adopt another method. We will make two contrasted suppositions: glaciers cannot erode, and glaciers can erode; we will consider the appropriate consequences of each supposition separately; we will next confront these consequences with the facts of observation; and then, according as one or the other group of consequences is verified by the facts, we shall be able to determine impartially which one of the suppositions is correct."

In such a problem as this it is evident that if glaciers cannot erode, we ought not to find any significant differences between the forms of glaciated and of non-glaciated mountains; but if glaciers can erode, we ought to find in glaciated mountains a whole series of peculiar forms, and these forms ought to be appropriately related to the form and movement of glaciers. The essential steps in the application of this method may now be outlined.

At this point the author discusses the mountain forms sculptured by stream erosion. These forms are illustrated in Fig. 1. The main argument then proceeds.

Deductions from Theories.—Now if glaciers have no erosive power, then maturely dissected mountains that have been glaciated should present no features significantly unlike those above described for mature non-glaciated mountains. But if glaciers have strong erosive power, special and significant features should be found in mountains where glaciers have had time enough to do their work. The most notable features of this kind that one would expect to find, may be stated as follows: A large part of the cross section of a glaciated valley would be included in the trough-like channel that was scoured out and occupied by the heavy, sluggish glacier; the bed of such a trough would have rock steps and rock basins similar to those in the bed of a river channel, but appropriately of much greater size; the sides or walls of such a trough would be comparatively even and parallel, like the sides or banks of a river channel; the troughs of small side glaciers would necessarily be of much less depth than the troughs of large trunk glaciers, and hence the bed of a side trough would hang hundreds of feet over the bed of the trunk trough; the valley sides above the trough would, in mountains of mature sculpture, be less steep than the trough walls themselves; the heads of the glacial beds would be broad-floored cirques, because the heads of glaciers are broad and leaf-like instead of being divided minutely like the headwater streams of rivers; the summits and ridges between cirques which head near each other would be sharpened into peaks and arêtes by atmospheric weathering, induced by the retrogressive glacial erosion of the ice in the cirques, and by the glacial widening of the troughs. Other features might be named, appropriate to glaciers of large or small size, or of short or long duration, but those here set forth are sufficient for a brief exposition.

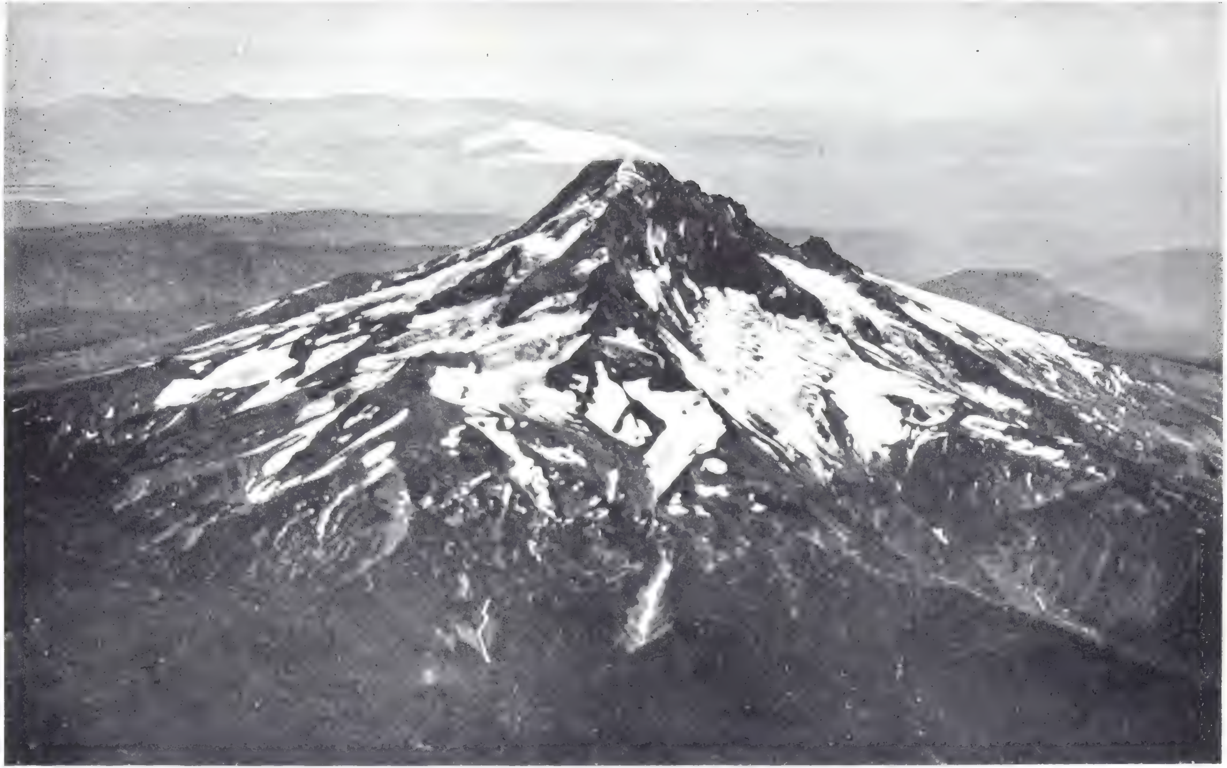
Graphic Illustrations of Glacial Sculpture.—The attempt is made in Figs. 1, 2, and 3 to present examples of the unlike features just described. The figures make no pretense of being drawn from actual mountains; but they are in a way made up from various observations, sketches, and photographs, and in



[illegible]

SMALL VALLEY GLACIERS ON VOLCANIC CONES

The Three Sisters, southern Oregon.



U. S. Army Air Corps

MOUNT HOOD WITH ITS TRAILING CLOUD-CAP

A young volcanic cone in Oregon, dissected by small glaciers. Its summit is 11,225 feet above the sea.

this respect correspond to the "deduced consequences" of the hypothesis that glaciers can erode, as announced in the preceding paragraph; for the consequences are not simply abstract deductions; they have been tested at nearly every step by observation. The figures undoubtedly need many amendments; they are hard and crude, yet they have some value in making the preceding paragraph clearer than it would be without them. Moreover, the figures ambitiously attempt to exhibit the changes that a given mountain mass would suffer from a pre-glacial time of normal sculpture, through a pronounced glacial period, to a post-glacial time in which the work of the glacial period has as yet been but little affected by the return of normal conditions; in this respect they are necessarily only ideal examples.

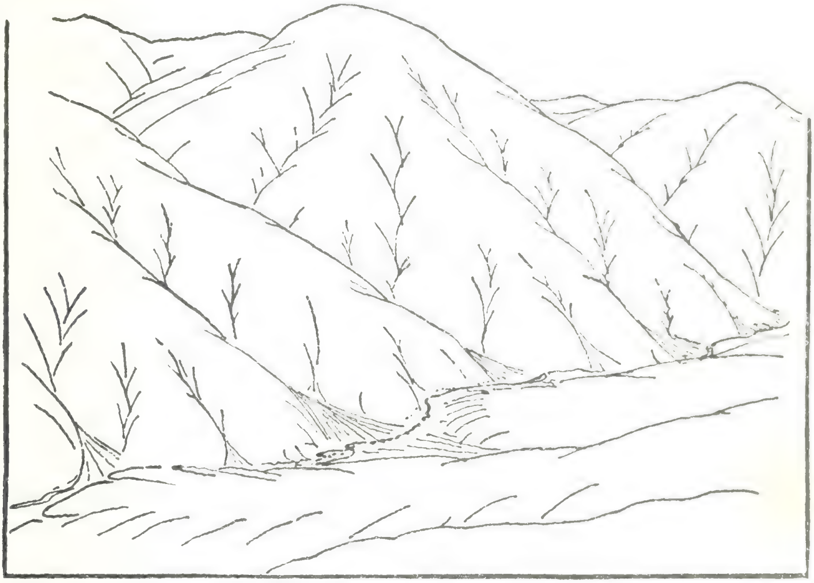


FIG. I.—A NORMALLY ERODED MOUNTAIN MASS, NOT AFFECTED BY GLACIAL EROSION.

Fig. 1 shows the rounded, dome-like forms of a subdued mountain mass. The cliffs and ledges of an earlier stage of normal erosion have been worn away, and the waste cover has been very generally extended over the graded slopes that now reach from valley bottom to mountain top. This stage of mountain sculpture was chosen because it is so well represented in the Sawatch range of the Rocky Mountains in Colorado in association with glacially sculptured forms, such as are illustrated in the later figures. Normally sculptured mountains of sharper form, like those of southern California, might have been taken had I seen them otherwise than in photographs. The main valley is widely opened; its floor is well graded to a continuous slope; its stream has no lakes or falls, but swings smoothly along a somewhat sinuous course between the spurs that come down with moderate slope from the higher ridges. The side valleys branch in a delicate fashion upwards, splitting the spurs into many spurlets; but all the streams and valley floors unite in accordant fashion at their many points of junction. The spurs are round-shouldered forms, exhibiting very few outlines by which their elusive curves may be represented; indeed, as here drawn, they have an undue resemblance to the sprawling feet of some huge pachyderm. I believe that if mountains of this kind had been more familiar to those who have discussed the question of glacial sculpture in the Alps, a closer approach to agreement on the question of glacial erosion might have been reached ere now.

Fig. 2 is intended to represent the accomplished work of a heavy glacial system on the mountain mass of Fig. 1. The main glacier has gained room for its broad current by wearing off the ends of the spurs that formerly entered the main valley from either side; and it has gained room for its heavy and deep ice body by excavating the valley floor to a greater depth than it had in pre-glacial time. The side glacier which enters from the upper left corner of the figure is manifestly less deep than the main glacier; hence, while the ice surfaces of the main and side ice streams unite at accordant grade, the beds of their troughs or channels cannot unite in that even fashion; for when the troughs are once scoured out to a satisfactory depth for the two unequal ice streams, further change of trough depth will be small. The smaller branch glaciers in the main mountain mass have enlarged the branch valleys that they occupy, and retrogressive erosion at the heads of these glaciers has transformed the tapering valley heads of pre-glacial time into bluntheaded cirques. The slopes of the spurs and summits have been greatly steepened, and the ridges and peaks greatly sharpened, by the active weathering resulting from glacial under-cutting in the branch troughs and cirques. On the extreme right another mountain is shown in which two cirques have been excavated, not to sufficient size to transform the preglacial dome into a sharpened peak, yet large enough to have encroached on the spur that separated them, and thus to have transformed part of it into a serrate ridge. Mt. Elbert, the highest summit of the Rocky Mountains within the United States, presents just this sort of a contrast to its slightly lower neighbor, La Plata peak, whose summit has been sharpened into Alpine form. If the glacial conditions here pictured should last long enough, it is not to be doubted that the mountains would in time be reduced to lower and gentler forms than are here presented in the toothed peaks and serrated spurs of the central mass; and eventually they might be worn down so low that the glaciers would slowly and spontaneously disappear, in consequence of the increasing mildness of climate thus produced—such being Tyndall's suggestion of the Alps; but the very fact that strongly glaciated forms, with the associated peaks and arêtes, now characterize the ranges that were heavily glaciated in Pleistocene time, suffices to prove that the glaciers did not disappear because of their own action in wearing down the mountains, but because of some external control of climatic change.

Fig. 3 illustrates the appearance of the mountains and valleys after the glaciers of Fig. 2 have melted away. Now there is a superabundance of detail; the difficulty in drawing is to select the most significant outlines and to omit the rest. The forms that rose above the ice streams in Fig. 2 are here reproduced without essential change. The spurs on the left are unaltered in form, but are somewhat worn down from their appearance in Fig. 1. The forms that were buried under the ice streams of Fig. 2 are here disclosed to the light of day. The troughs of the smaller branch glaciers have ungraded floors, on which rock basins and rock steps alternate. The troughs of the large side glacier and of the main glacier are better smoothed. Alluvial fans are already accumulating on their sides, just as they are in the Alps and in other glaciated ranges. The fact of such accumulation suffices to prove a strong change from the conditions under which the troughs were excavated to the conditions in which they are now filled up. The truncated spur ends now continue downwards in the over-steepened trough sides and curve at the base into the *U*-shaped trough floor. The junctions of the various glacial troughs, to which the name of valleys is of course ordinarily applied, are essentially discordant. The trough of the large side glacier hangs

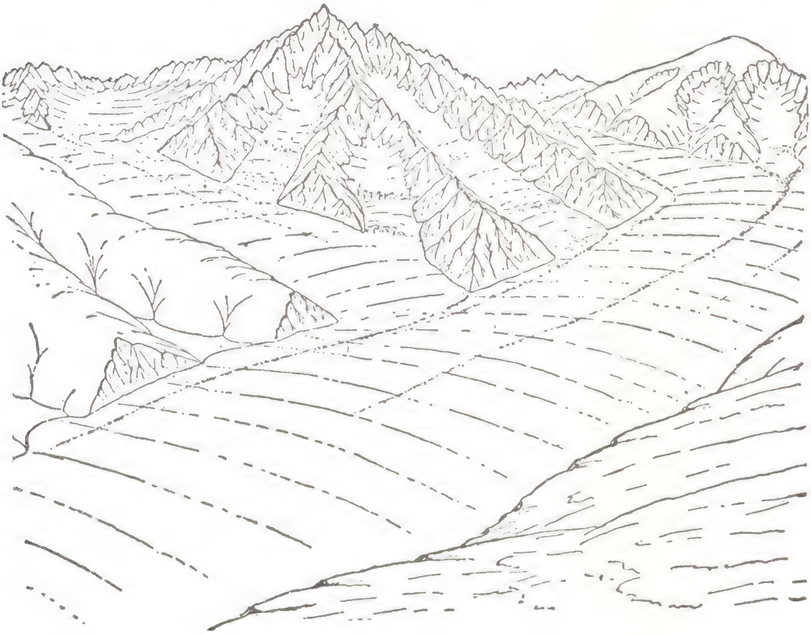


FIG. 2.—THE SAME MOUNTAIN MASS AS IN FIG. 1, STRONGLY AFFECTED BY GLACIERS WHICH STILL OCCUPY ITS VALLEYS.

high above the floor of the main glacier trough; the troughs of the smaller branch glaciers hang over the trough of the large side glacier. If the main trough could be followed down to its end, a large basin should be shown, occupied by a lake, and inclosed by morainic walls. As time progresses, all these peculiar features will be changed to normal features. A beginning of such changes is seen in the little slits by which the mouths of the hanging valleys are already beginning to be cut down; in the filling of the lakelets in the rock basins of the smaller branch troughs; and in the rapid wasting of the sharpened ridges and peaks, by which they will in time be rounded again; but the small amount of work thus far accomplished proves that the time since the evacuation of the district by its glaciers is comparatively short.

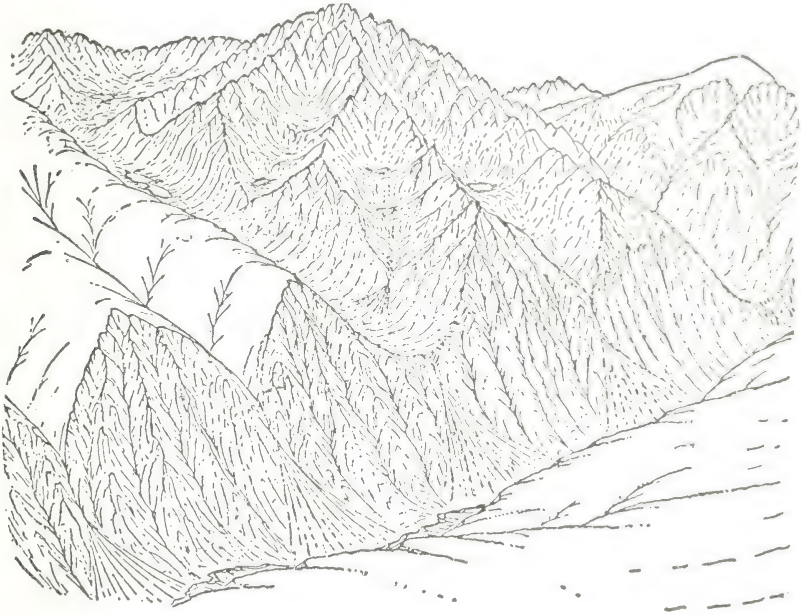


FIG. 3.—THE SAME MOUNTAIN MASS AS IN FIG. 2, SHORTLY AFTER THE GLACIERS HAVE MELTED FROM ITS VALLEYS.

It is manifest that if a vigorous glacial system should soon again come to occupy the mountainous area of Fig. 3, it would produce relatively small changes compared to those by which the forms of Fig. 1 have been altered to those of Figs. 2 and 3; for the glacier system of the second epoch would find the valley troughs so well adapted to its needs that there would be relatively small necessity of modifying them. The amount of sculpture effected in a first glacial epoch may therefore be reasonably estimated as of much greater volume than in a second glacial epoch.

Consequences of Theories Confronted with Facts.—When glaciated mountains are visited with the unlike consequences of the contrasted supposition above stated in mind, there can be little doubt whether glaciers are effective eroding agents or not. As far as the glaciated mountains of the world have been explored, it is found that they possess a large number of peculiar forms, which differ most strikingly from the forms due to the normal processes of erosion; it is further found that these peculiar forms are distributed with respect to one another in a most systematic and significant manner; and it is finally perceived that the peculiar forms are essentially similar to those above described and figured as producible by glaciers, under the supposition that glaciers have effective erosive power and that they have had time to use it. Thus the efficiency of glaciers in carving glaciated mountains is demonstrated by essentially the same method that has so thoroughly demonstrated the efficiency of the normal erosive agencies in carving non-glaciated mountains.

It can hardly be questioned that if, as Andrews has well pointed out, students of mountains had not come upon glaciated forms until after they had seen a good variety of normal forms, the exceptional quality of the needle peaks and the serrated ridges, of the rock basins and the rock steps, of the truncated spur ends and the over-steepened trough walls, of the hanging side valleys and the over-steepened main valleys, would have been sooner appreciated. But, as a matter of fact, the Alps and other strongly glaciated ranges have been taken as types of mountain form from a time when there was no question at all of glacial erosion; and as a consequence the exceptional quality of many Alpine forms has passed relatively unnoticed. The literature of the subject shows that the peculiar features which characterize glaciated mountains are not regarded as exceptional by observers whose experience has been gained chiefly in mountains like the Alps; yet, on the other hand, the peculiar features of glaciated mountains are very impressive when they are seen by one whose standard of normal mountain form has been established in non-glaciated mountains, and still more so when they are considered in view of the reasonable consequences of the supposition that glaciers can erode their valleys or can modify preëxistent normal valleys. . . .

The Origin of Cirques

Although we are now in no doubt about the power of ice to erode, we are still far from understanding the way in which a cirque is formed. W. D. Johnson, a member of the U. S. Geological Survey, made some observations on the glaciers of the Sierra Nevada which led him to believe that these symmetrical amphitheaters are cut by sapping of the rock at the bases of bergschrunds. Some of his observations (Johnson, 1904, pp. 573-575) make interesting reading, but it must be remembered that his results are still mere theory, backed up by a certain number of facts. His conclusions are accepted by many; but only further study will show whether Johnson was right or wrong.

Among the numerous crevasses or schrunds of several diverse systems sharply lining the snowy surface upon which I looked directly down as upon a map, one master opening, the *Bergschrund* of the Swiss mountaineers, paralleled the amphitheater wall, a little out upon the ice. In detail it was ragged and splintered, but its general effect was that of a symmetrical great arc. I had already in mind, vaguely formulated, the working hypothesis that the glacier makes the amphitheater; that it is not by accident that glaciated mountains, and such mountains only, abound in forms peculiarly favorable to heavy snow-drift accumulation. My instant surmise, therefore, was that this curving great schrund penetrated to the foot of the wall, or precipitous rock slope, and that a causal relation determined the coincidence in position of the line of deep crevassing and the line of the assumed basal undercutting.

So much of assumption, so plausibly grounded, rendered direct observation at this critical point on the glacier floor compellingly desirable; and, returning to camp for all hands and the pack ropes, the rather appalling task was in fact very easily accomplished.

The depth of descent was about one hundred and fifty feet. In the last twenty or thirty feet, rock replaced ice in the upcanyon wall. The schrund opened to the cliff foot. I cannot say that the floor there was of sound rock, or that it was level; but there was a floor to stand upon, and not a steeply inclined talus. It was somewhat cumbered with blocks, both of ice and of rock; and I was at the disadvantage, for close observation, of having to clamber over these, with a candle, in a dripping rain, but there seemed to be definitely presented a line of glacier base, removed from five to ten feet from the foot of what was here a literally vertical cliff.

The glacier side of the crevasse presented the more clearly defined wall. The rock face, though hard and undecayed, was much riven, its fracture planes outlining sharply angular masses in all stages of displacement and dislodgment. Several blocks were tipped forward and rested against the opposite wall of ice; others, quite removed across the gap, were incorporated in the glacier mass at its base. Icicles of great size and stalagmitic masses, were abundant; the fallen blocks in large part were ice-sheeted; and open seams in the cliff face held films of this clear ice. Melting was everywhere in progress, and the films or thin plates in the seams were easily removable.

These thinning plates, especially, were demonstrative of alternate freezings and thawings, in short-time intervals, probably diurnal. Without, upon the cirque or amphitheater wall, above the glacier, such intervals would be seasonal. Thus, apparently, to generalize from observation at a single point, the arc of the bergschrund foot, and the coincident arc of the cirque-wall foot, is a narrow zone of relatively vigorous frost-weatherings. The glacier is a cover, protective of the rock surface beneath it against changes of temperature. Probably the bed temperature does not fall below that of melting ice. Hence, if (in summer) the bed at the wall foot is exposed, through the open bergschrund, to daily temperature changes across the freezing-point, frost-weathering must be sharply localized. The glacier will be efficient as the agent for debris removal; the result, therefore, must be quarrying and excavation, and basal sapping.

The amphitheater floor has been described as characteristically reversed in grade, though at a slight angle, and ponded backward against its head wall. It may be assumed that the disrupting action of frost at the bergschrund foot is directed against the floor, as well as against the cliff. Likely enough, also, the glacier is a highly efficient agent for removal, supplementing, by "plucking," the initial rupturing work of frost. Its plucking action may be directed downward as well as backward; but downward action, at an early stage, will be defeated by the rapidly increasing difficulty of waste removal. The great arc-form crevasse at the glacier head, therefore, may be the indirect cause, not merely of recession of the canyon head at a low grade into a high grade, but of recession at a grade declining from the horizontal. Apparently there is a limit to such extension—a limit the earlier reached, the sharper the acclivity of the upland surface into which channeling is extended; and the head wall, in consequence, breaks back into steps, successively shortening in length of tread. The rearward steps may continue to be marked by schrunds rising to the glacier surface; living glaciers, in fact, are often characterized by "cascades" in their upper courses; but sharply defined cross-cliffs, in empty glacial canyons, are rarely to be found far down-stream. Presumably they are so deeply buried there as to be wholly left to the dulling influence of scour.

The "rock-basin" lakes of the bare floors toward the head have received more attention than the great bowl of the amphitheater itself, the most phenomenal of all constantly recurring mountain forms; but I suspect that they are even more significant than has been supposed.

BIBLIOGRAPHY

Chapter IV—Glaciers and Glaciation

W. M. Davis, *The Sculpture of Mountains by Glaciers.* Scottish Geographical Magazine, vol. 22, 1906, pp. 76-89.

John Finch, *Geological Essay on the Tertiary Formations in America.* American Journal of Science, vol. 7, 1824, pp. 31-43.

Willard D. Johnson, *The Profile of Maturity in Alpine Glacial Erosion.* Journal of Geology, vol. 12, 1904, pp. 573-575.

Sir Charles Lyell, *Principles of Geology.* 9th Ed., New York: Appleton, 1860, pp. 222-223, 223-226.

Benjamin Silliman, Notice of Horace H. Hayden's Geological Essays. American Journal of Science, vol. 3, 1821, p. 49.

Benjamin Silliman, quoted by H. E. Gregory in *A Century of Science in America.* New Haven: Yale University Press, 1918, pp. 133-134.

A. E. H. Tutton, *The Natural History of Ice and Snow.* London: Kegan Paul, Trench, Trubner & Company, 1927, pp. 77-78, 130-131, 239-240.

John Tyndall, *Hours of Exercise in the Alps.* New York: Appleton, 1897, pp. 75-79, 243-247.

CHAPTER V

GROUND WATER

NATURE uses the surface waters of the Earth as the sculptor does a chisel, to form from out the shapeless stone the numberless details of the landscape that delight our eyes, and covers the favored regions with the green robe of vegetation. How different, though, when water is lacking! Heat and cold and wind are then the only tools at her command and, though she fashions thus many of her sublimest results, such lands are barren and life is hard for all creatures unless water can be obtained.

Eliot Lord (1883, pp. 1-2) has described the "Great American Desert" of the older geographers in vivid phrases:

> The cloud banks blown overland from the Pacific are thrown in masses against the bristling teeth of the Sierra Nevada. Repelled at every point, they break in rain, snow, and hail among the mountains. Winter storms tear their way sometimes through the unyielding barrier and bury the hill-tops beyond under eddying snow-drifts, but a covering is rarely cast over the deformity of the deserts below. Looking eastward from any bare crag above the tree-belt, the eye sees no end to these desolate wastes, and beyond the range of vision they stretch unbroken for hundreds of miles. A few shallow rivers, fed by the mountain snows, wander in narrow beds through the cañons and valleys, vanishing at length in alkaline sloughs, or pouring their wasted streams into brackish lakes; broken fringes of green mark their winding courses—the only relief to the somber tints of the landscape.

Since the day when Eliot Lord looked eastward from the Sierra's crest the latent fruitfulness of that and many another desert area has been rendered fecund by contact with water brought long distances overland or won from below the parched surface of the ground. For water lies beneath the driest waste of blowing sand and can sometimes be obtained in quantities sufficient to support life.

There is always mystery attached to the desert oasis, a spot made green by fresh water in a land where little rain falls and few streams survive; where nearly all pools are bitter and sterile. Whence comes this living water? Does it lie in vast lakes or in rivers running beneath our feet? In places, yes: for there are deserts where rainfall is plentiful but where the water disappears into the cavernous rocks, and, flowing in measured courses or standing in dark, silent pools, it leaves the surface barren. But usually this is not so. The rainwater descends through the surface rock and soil and spreads out to fill the numberless crevices in the rock and the spaces between the grains. Its travels then are interrupted and difficult to trace.

Belief in the inscrutable character of the subterranean movements of water is reflected even in the laws of the United States. When they were enacted it was apparently taken for granted that the flow of water in the rocks beneath the surface was so mysterious and indeterminable that no one could be expected to realize or be responsible for the consequences of an act which might harmfully affect a neighbor's property.

To be sure, when subterranean water flows in definite streams it is subject to the same laws as surface water; it cannot be wholly diverted by one man for his use, but other waters are regarded as "percolations" or as resting stationary in the strata and belong to the land as do other minerals. C. H. Shamel (1905, p. 18) recounts a dispute that arose between a tanner whose business required the use of water from a spring on his property, and the owners of a copper mine on an adjacent farm. When the water that flowed into the mine shaft was pumped out the tanner's spring ran dry and he sued the copper company. The court decided, however, that the water reached the shaft as "percolations" which it was impossible to avoid disturbing without relinquishing the use of the land. It said: ". . . the law has never gone so far as to recognize in one man a right to convert another's farm to his own use, for the purposes of a filter." In other words, a man is not expected to let all the rain that falls upon his land percolate through and escape to his neighbor's land

PLATE XI

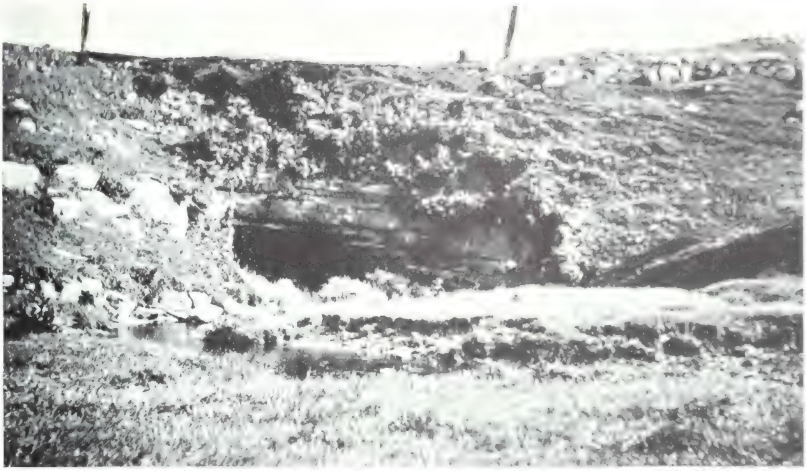


Photo D. W. Johnson

A. ENTRANCE TO A CAVERN

The bottom of the valley occupied by the river before it began its underground course shows above the cave entrance.
The Sinks, near Osceola, West Virginia.

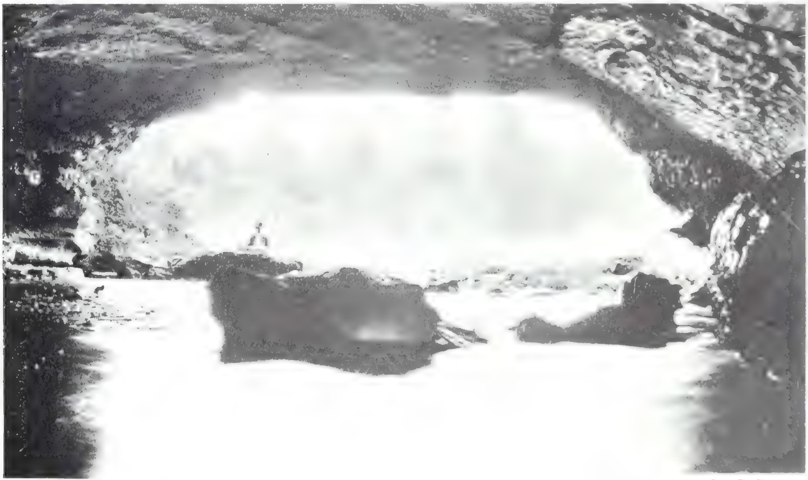
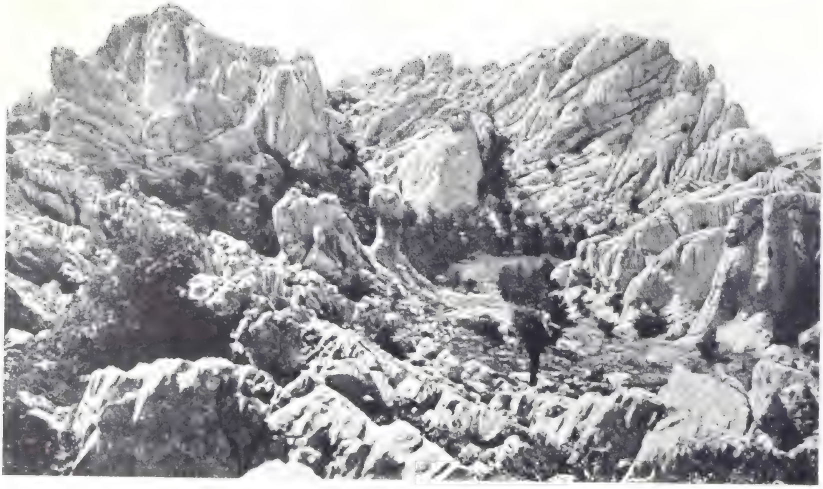


Photo D. W. Johnson

B. EXIT OF AN UNDERGROUND RIVER

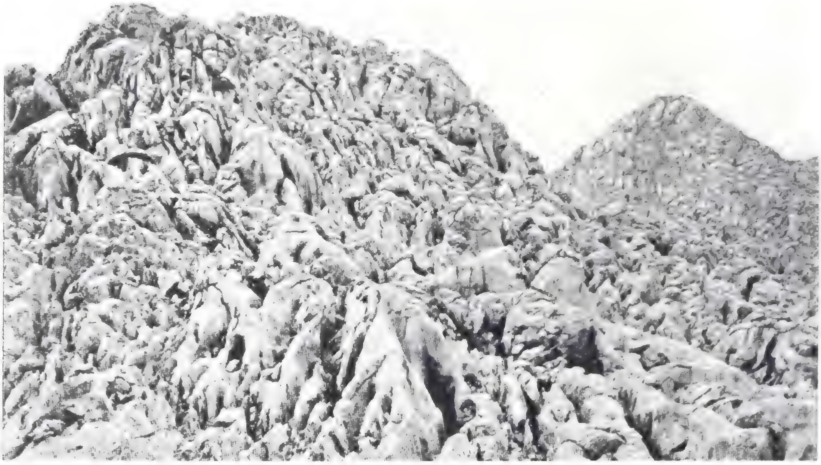
The Sinks, near Osceola, West Virginia.



Courtesy of the Geographical Review, published by the American Geographical Society of New York

A. EROSION FORMS IN THE DINARIC KARST

Small hollows harboring a thin covering of soil surrounded by barren limestone.



Courtesy of the Geographical Review, published by the American Geographical Society of New York

B. A WILDERNESS OF BARE STONE

Irregular, chaotic forms made by solution of limestone in the Dinaric Karst.

for his neighbor's use, else no one could dig a cellar or a ditch without danger of being dragged into court.

Needless to say much has since been learned regarding the action of the water that passes down into this mysterious zone. It has been carefully studied because it is important in many ways; in agriculture and reclamation projects, as a source of water for drinking and washing, and because of the important geological work it accomplishes.

Lower Limit of Ground Water

It is natural that mines and boreholes should teach us much about the water in the ground and, shallow as man's attempts to penetrate the Earth may be, they show that most of this water is confined within a zone a few thousand feet deep. The water that saturates the rock up to a definite level a variable number of feet below the surface, the bitter enemy of miners, peters out irregularly four or five thousand feet below. There are, of course, well-defined channels along which water descends much deeper, and when layers of sedimentary rock slope down from the surface they sometimes bear water far below the level mentioned, but the water in active circulation through the great mass of the rock is confined to the upper few thousand feet.

Artesian Wells

It is always surprising to see water spouting out of a pipe sunk thousands of feet into the Earth, but it is perfectly natural and easily understood if one keeps in mind the principles involved and follows in the mind's eye the course of that water from where it falls as rain upon some higher ground far distant, until it returns to the surface through a man-made vent. The quotations (Chamberlin, 1885, extracts from pp. 132-168) that follow explain why water sometimes flows uphill:

> If there lingers in the mind any sense of marvel at the flow of artesian wells, it is best to cast it away at the outset. Artesian flow is but an expression of the common law of flowage, made a little unusual, it is true, by its special conditions. Any seeming strangeness springs from our partial observation. We see but a part of the stream. The rest lies hidden in the earth's

depths, a realm which the imagination is prone to people with mysteries. Moreover, the part we do most see is a *rising* stream, that comes gushing up in the face of the dogma that water "never runs up hill." But water flowing up hill is one of the commonest facts of nature, an every day, an everywhere occurrence, illustrated in every brook, rill, and river, not to say spring. Stir up a little trash in the bottom of any deep pool in a brook, and see how readily it is borne up the slope of the pool-bed, and out over the shallows below. Disturb the bottom mud above a dam, and watch it ascend the steep slope, and pass over the weir.

Certain portions of the water of every stream are always "running up hill," though its average mass is moving down.

The bottom layer flows up and down according to the inequalities of the bed, while the top layer declines more uniformly with the surface slope. In proportion as the stream is rapid and crooked, these layers exchange places, and there is a tortuous upward and downward flow, in addition to that directly enforced by the bottom inequalities, though all are largely due to these. The flowing up is merely a way of flowing down, i.e., the rising of a part permits the descent of a greater portion, of the greater descent of an equal or less part. No portion would rise, if it were not forced up by a superior portion pressing down. In the artesian stream, we only see the rising column issuing from the earth, and the brooklet that flows away. The more potent descending volume that forces the flow is concealed. This it is the mind's task to picture clearly. . . .

Rainfall.—For the ultimate source of these fountains we are led up manifestly to the clouds, and the chief question relates to the adequacy of the supply they pour out upon the collecting area. There lurks an ambiguity, however, under the term adequacy. To what adequate? To furnish all that we can use and waste, or all that the strata may drink? The amount that may be desired is diverse in the highest degree, embracing moderate needs of the farmer for his kitchen and cattle, the larger service of the manufacturer for his different uses, the great consumption of cities for their baths, sewers, lawns, and streets, and the almost limitless demands of irrigation. If there were no limits to the available supply it would be difficult to set bounds to the drafts that would be made upon it. On the other hand, the amount which the strata can drink in, carry underground, and deliver through the well has much more definite limits; and this is clearly the better standard by which to judge the adequacy of the rain-fall, for when it has furnished to the strata all that they can take and deliver, it can do no more. It is adequate to the existing conditions, if not to our possible desires. Any failure to yield more is chargeable to the earth and not to the sky.

Still, in the absence of a full knowledge of the subterranean conditions, the possible competency of the rainfall may be considered. . . .

Contrasted Ratios of Supply and Demand.—Very generous or very meager possibilities will result from computation, according to the region put under estimate and the want to be supplied. In the more humid districts the wants of the land are satisfied and the artificial demands are limited chiefly to domestic and sanitary uses. The supply is great and the demand small. In the more arid regions the land is thirsty also, and there is an enormous demand for irrigation. The supply is small and the demand great. So, unfortunately, the greatest demand and the least supply are mated.

The ratio of rain-fall to domestic needs is usually high. There falls upon every 50 feet square in average habitable regions more than the highest per capita allotment of cities, even under a Parisian régime. But the ratio of rain-fall to agricultural demands, though sometimes high, is often low. The precipitation upon the 50 feet square falls far short of furnishing food-support for an individual. The shadow of an ox covers half space enough to collect the water he drinks, but it would be a very partial supply for the sward he grazes.

While, therefore, in humid regions the rain-fall, considered apart from loss, is usually ample for the demands which there commonly arise, a little inspection shows that in arid regions it is quite inadequate for the demand which *there* arise.

Limits in Depth.—The vitality of a false notion is often surprising. It is sometimes crushing to our faith in the survival of the fittest. A striking illustration is found in the wide-spread popular delusion that an abundant flow may always be found "if you only go deep enough." When we consider that rainfall is the great source of the waters of the land, and that the strata, as a rule, become more compact as depth increases, it is apparent that a very nearly opposite presumption should displace this fallacy. It doubtless arises from the fact that the immediate surface beds are more or less dry, and that it is necessary to penetrate some small distance to reach the subterranean water-bed. It is not realized that when this is once fairly reached the most richly supplied aqueous horizon is found. The beds below grow closer in general, and present less opportunity for accumulation. If, in imagination, the relatively dry surface was removed the rest of the earth might be conceived as most copiously filled with water in the more open upper portion, and less and less permeated below, because less and less open to receive water. This is, of course, only a general law, subject to much modification, according to the kinds of rock which overlie each other in succession.

In view of this general presumption, it is folly to sink deep wells without some definite knowledge that a rock of porous nature lies below and presents the requisite conditions for supplying a fountain. The occasional luck of ignorance may find a flow, but it is not soothing to our pride of popular intelligence to note how thickly our land is punctured by needless follies, largely encouraged by the above fallacious conception.

Preliminary to sinking a well, as complete knowledge of the underlying strata as it is possible to obtain from the usual methods of geological inquiry should be gathered, and the depth of the well limited to that necessary to reach the most productive stratum. To be sure, there are regions in which, in the absence of specific knowledge, or when such as can be obtained is indecisive, the sinking of a deep well to test the strata is warranted by the importance of a favorable result; but the uncertainties of the issue and the financial hazard of the undertaking should be frankly faced. It is not to be inferred from these conservative remarks that failures do not result from the opposite cause, that wells do not often come short of success by stopping short of the proper horizon. The existence of such failures only adds to the importance of specific knowledge in lieu of broad proverbs and loose maxims.

The succession of strata is so various in different regions that general rules are few. There is one, however, of wide application whose observance would save the useless expenditure of large sums. The Archæan rocks . . . are exceedingly unpromising of success in themselves, and do not overlie productive beds. Whenever, therefore, in the progress of drilling these are struck, work should cease, unless there are specific local facts warranting a deviation from the rule. A provision to this effect should be inserted in all contracts, since it is in the interest of both parties, for the drilling is usually very difficult and unremunerative at any ordinary rate per foot, while, there being no rational prospect of good results to the owner, the amount he pays, however unremunerative to the driller, is a dead loss to himself. It is not sufficient to insert the term *granite* instead of *Archæan rock,* as is sometimes done, since quartzites and other crystalline rocks, not fairly embraced under the term granite, even in its more extended sense, are included in the Archæan series, the penetration of which would prove alike unprofitable to driller and owner.

Locally there are other formations at which drilling should cease, either because no productive beds occur below, or because they are known to lie at unavailable depths. Specific knowledge of such local conditions is requisite for guidance in these instances.

The glacial deposits that mantle the state of Iowa are penetrated by numerous shallow artesian wells spread about in many local artesian basins. They are not unusual in any way with the exception of one—the "Jumbo" well of Belle Plaine—which achieved notoriety through the havoc it wrought at the beginning of its career. The details of mismanagement and the resultant disaster are explained by W. H. Norton (1897, pp. 350-352) as follows:

> . . . The notoriety of "Jumbo" of Belle Plaine was strictly that of a member of the criminal classes, and began with his resistance to control, and lasted only until his final imprisonment. Six artesian wells had previously been drilled in the drift at Belle Plaine. . . .
>
> The seventh well, "Jumbo," was drilled on lower ground than any of the others and reached the water-bearing stratum of sand and gravel at 193 feet.
>
> Local historians of the well, which they please to term "the eighth wonder of the world," state that the beginning of trouble lay in the fact that the driller attempted to use the force of the flow in reaming out the two-inch bore which he had put down for want of a larger drill, to three inches, the dimension specified in the contract. This task the water speedily accomplished in the unindurated clays and sands, but not stopping there went on and soon enlarged the bore to over three feet in diameter. Through this shaft the water boiled up in a fountain five feet in height—the press reports giving several hundred feet as the height of this fountain were exaggerated—flooding streets and yards and covering them with sand. It is estimated that from 500 to 1,000 car loads of sand were discharged from the well. The quantity was certainly so great that only with the greatest effort could the ditches be kept open to carry off the water. Gravel and small pebbles of northern drift were thrown out, and some pieces of fossil wood two and three feet long. The maximum flow of water was variously estimated at from 5,000,000 gallons to 9,000,000 gallons per diem. Two weeks after the well was drilled Chamberlin cal-

culated its discharge at 3,000,000 gallons for the same period. The enormous flow rapidly drew down the head of the other wells until it sank beneath the surface.

The attempts to case and control the well continued from August 26, 1886, the date when water was struck, to October 6, 1887, when the task was successfully accomplished.

During this time the well, 193 feet deep, devoured, as local historians tell us, 163 feet of eighteen-inch pipe, seventy-seven feet of sixteen-inch pipe, sixty feet of five-inch pipe, an iron cone three feet in diameter and twenty-four feet long, forty carloads of stone, 130 barrels of cement, and an unestimable amount of sand and clay.

The well was supposed by many to tap an aqueduct leading from some large and distant body of water, but with such vagaries the reader will have little patience. Of this artesian field Call says that "there are indications which point toward the existence in this area either, first, of a great preglacial valley which has become filled with morainic materials, or, second, to the existence of a great fault." He further suggests "that the water may be derived from the Cedar River, which he considers may be tapped below Waterloo, the water finding its way southward through a very wide and deep channel, from which rises the water at Belle Plaine. "Certain it is," says he, "that some unusual and abundant water supply prevails in that section. The rainfall is not above the mean of the state, and no other subterranean source seems probable."

On the other hand, Chamberlin states after a personal examination of the wells, that "it is not necessary to suppose any unusual subterranean source, either in area or kind. Nor is it necessary to suppose a distant origin. The head is not greater than could be supplied by the country adjacent on the north, which is the probable supply-ground.

"It is simply a flowing drift well, run rampant for want of control. It has its phenomenal feature in its magnitude and its lesson in its expensive and destructive career through injudicious handling."

This conclusion is based on careful estimates, which show that the upper edge of the water-bearing stratum, the area of intake which supplies the Belle Plaine well, need not exceed 400 acres in extent.

It is probably unnecessary to add that the author regards the Belle Plaine area as a normal artesian basin in glacial drift, and does not sympathize with any view of the derivation of its waters through a great fault or by the subterranean diversion of a river.

Quality of Ground Water

A vast water supply is of no avail if it is unfitted for its intended use. This is most obvious in the case of water for drinking purposes. The following extract (Gregory, 1918, pp. 141-143) considers this point:

> *Relation of the content of water to its use.*—The quality of water depends upon the substances which it contains either in solution or in suspension. These substances may be solids, liquids, or gases and may be organic or inorganic. The quality of the water is of great practical importance as affecting its adaptation for various uses, but different properties are important in different uses. Therefore, to say that water is good or bad has little significance unless the purpose is specified for which it is good or bad, as for drinking, washing, use in steam boilers, or irrigation. In military water supplies drinking and other personal uses are the most important, but use in steam boilers and for other industrial purposes are also of much consequence.
>
> *Sanitary quality of surface water.*—Surface water is a great natural scavenger which picks up and carries away, chiefly in suspension, loose particles of mineral matter and also vegetable and animal refuse. The loose particles of mineral matter make the water roily, which renders it objectionable although not necessarily harmful for drinking and causes it to make deposits in boilers and to some extent to produce foaming in boilers. The vegetable and animal refuse is objectionable for

drinking, particularly if it includes excreta which may contain disease germs such as those of typhoid fever. As persons who are apparently healthy may be carriers of these germs, any water from a source that may have been contaminated by human excreta is dangerous for drinking unless it has been purified by natural or artificial means. The drainage from populated districts is obviously unsafe and in former years caused numerous epidemics, and even the apparently pure water of streams from sparsely settled mountain regions sometimes conveys typhoid germs from isolated cases to communities that depend on the streams for water supply.

Sanitary quality of ground water.—When water is absorbed and percolates through the earth it loses nearly all of its suspended matter by filtration through the small interstices of the rocks, and hence, when it reappears from springs or wells it is generally clear. It acquires the temperature of the earth's crust, which at depths of 25 to 100 feet is about the mean annual temperature of the atmosphere in the region. Nearer the surface its temperature fluctuates slightly with the season; at greater depths the temperature increases—in most regions at the rate of 1° F. for 50 to 100 feet increase in depth. Hence, in regions having a temperate climate ground water from moderate depths is not only clear but also cool. For this reason it is in much popular favor and is assumed to be pure, notwithstanding the fact that clear cool water may contain deadly disease germs.

The removal of matter held in suspension in the water is due mainly to the entanglement of the suspended particles among the grains of the rocks through which the water passes. The efficiency of this process depends largely on the size of the interstices, on the pressure gradient, and on the temperature of the water. The slower the filtration the more effective it will be, fine material is more effective than coarse, and low-pressure heads and low temperatures better than high ones.

In ordinary materials and with waters free from sediment there is relatively small decrease in the number of bacteria.

Where sediment of any sort is present in considerable amounts, however, many bacteria are entangled in the filter and remain behind with the residue. Free oxygen is present in the interstices above the water table and is in solution in the water for some distance below the water table. Either by direct chemical action or through the influence of bacteria it attacks and breaks down the impurities, reducing them to harmless mineral compounds. Even more important than the oxidation of impurities by the aid of bacteria is the work done by the so-called nitrifying bacteria, which not only break down the organic polluting materials but destroy most of the disease-producing organisms. Under artificial conditions, as in filtration plants, the action is almost perfect, 99.5 per cent. or more of the dangerous bacteria being removed; under natural conditions, however, the action is less complete. In brief, polluted ground waters are more or less purified through the removal of their suspended matter and a part of their bacteria by entanglement among the grains of the material through which they pass, by oxidation, and by nitrifying bacteria, but more or less polluting matter remains in the water for a considerable length of time.

The alternation of layers of materials of different texture and even the stratification of uniform materials tend to obstruct the downward passage of water and to confine pollution to the upper part of the zone of saturation—the part immediately below the water table. For safety from pollution wells should be tightly cased and carried to a considerable depth below the water table.

Where a single source of pollution exists and only a small amount of polluting matter enters the ground the contamination in sandy deposits does not commonly extend more than 150 feet from the source, provided the water is not pumped in great quantity. Where there are several sources of pollutions and large amounts of polluting matter are introduced into the ground the contamination may extend in porous materials for some hundreds or even thousands of feet, especially where the ground water moves with considerable velocity. Water may flow rapidly and for long distances through caverns and joints in limestone or other hard rock or through the large openings in coarse gravel, without being filtered. Although ground water is generally purified within a moderate distance from the place where it is absorbed, very large allowances for safety must be made on account of the variable and somewhat indeterminate conditions that affect purification, so that generalizations as to distances required for purification are of little practical value.

Limestone Caverns

Caverns exist in all extensive areas of limestone. Many of these caverns are famous throughout the world because of their size or because of the beauty of the formations revealed when a light dispels their eternal night. These caves draw many visitors yearly and are inspiring enough when their true dimensions are known. But there is some circumstance connected with these subterranean regions that leads the most truthful to exaggerate, and the prosaic surveyor has dispelled more than one illusion of immensity. H. C. Hovey (1882, pp. 18-21) cites cases in which man's imagination has run wild. He says:

> An example or two may serve to show how hard it is sometimes to get, from others, the exact truth concerning those subterranean regions that mankind have ever invested with awe, and amid whose profoundest depths they have even located the fires of Tartarus and the asphodel meadows of Elysium.
>
> The gulfs of Norway have already been mentioned. Eldon Hole may be put in the same category. This is a famous pit in the Peak of Derbyshire, about which Hobbes wrote in Latin and Cotton in English. The latter thus testifies in verse:
>
> "I myself, with half the Peak surrounded,
> Eight hundred, four score and four yards have sounded;
> And though of these four score returned back wet,
> The plummet drew and found no bottom yet!"

In other words the poet's measurement found no bottom at the astounding depth of 2,652 feet! Probably Mr. Cotton let the rope coil on the bottom, mistaking the weight of it for that of the plummet—a mistake actually made by a civil engineer in Kentucky, who reported a pit to be 300 feet deep, which afterwards was proved to be but about 90 feet! Concerning the Eldon Hole, it is further stated that the Earl of Leicester hired a man to descend, who, after going down 750 feet, was drawn up a raving maniac, and died in eight days. Very likely he imitated the Knight of La Mancha, when in the Spanish Cave, who ensconced himself on a convenient shelf, and let the rope dangle as far as it might below, while he dreamed the rest of the adventure. At all events when Mr. Loyd, a member of the Royal Society, took it in hand to sound the bottom of the Eldon Hole, he found it at the exact depth of 186 feet, and told the story in the Transactions of the Society. The currents of air and water flowing through its fissures probably connect with the lateral caverns for which Derbyshire is famous. The largest of these, the Peak Cavern, at Castleton, runs horizontally 2,250 feet into the mountain, and has six capacious chambers and a lake. Another goes by the name of the Speedwell Mine, because miners blasting for lead ore, accidentally opened a door into one of the finest caverns known. The visitor goes down 106 stone steps, embarks on a canal five feet wide, and pulls himself along by pegs in the wall for a quarter of a mile to a chasm down which a cataract plunges with a deafening noise. The dome over this pit is said to be 300 feet high, and is very grand and solemn. It is estimated that 40,000 tons of material from the mine have been cast into the chasm, without seeming to make any difference in its depth.

The Adelsberg Grotto, in Carniola, Austria, is generally pronounced the largest in Europe, and the most incredible stories are told as to its magnitude; and yet a recent official survey reduced its "many miles" to exactly 10,142 feet. Its magnificent chambers with imperial names, its fine stalactites, and the mysterious river heard murmuring in its recesses, attract thousands of tourists annually. It is now known to be excelled in actual size by the Aggtelek Cave, in Hungary, which is about 20,000 feet long.

Why is it that men are always tempted to magniloquence in attempting to describe subterranean wonders? We smile at the glorious account, in the Tipperary *Free Press*, of a cave in Ireland, found in 1833, whose chambers are "wider than angels' ken," one of them being "nearly a mile in circumference, and another fully three miles around;" and we have grim satisfaction in knowing that before the relentless surveyor the one shrank to a room 90 by 150 feet, and the other to a room 100 by 250.

And yet it becomes us to indulge our humor in moderation, remembering that "cave miles" are proverbial in America, and that we, too, on this side of the Atlantic have been made the occasional victims of perverted ingenuity. A writer in a popular journal, this very year, in giving the dimensions of a certain cave that is known to be less than 2,000 feet long, mentions two avenues in it one 10 and the other 13 miles in length! Among the many hoaxes perpetrated at the cost of a credulous public, the most notable are those invented about the Grand Crystal Cave, and another near Leitchfield, both in Kentucky; whose subterranean seas of breadth immense and swarming with blind fish, whose well-paved carriage-roads many miles long, were as nothing in comparison with their wonderful pyramids, Masonic altars and sculptured sarcophagi!

It seems hardly necessary to expose these amazing and amusing frauds; but the reaction from them should lead us to welcome statements from competent geologists and civil engineers, prepared to furnish exact information on matters about which the imagination is so ready to run ahead of the tape-line and level.

Caverns as Ancient Dwelling Places

Such caverns teach us more than just the workings of underground water. Many caves were used as habitations by primitive man and reveal the tools he used and the food he ate in the heaped-up refuse on the floor, covered over by younger layers and often by the rock itself, the stalagmites that formed later. The following passages from H. C. Hovey (1882, pp. 37-39, 41-42) outline what can be learned from such ancient dwelling-places:

> Imagine a cavern that had been used as a dwelling-place from the creation of man until now; the formation of dripstone going on in the meantime, securely sealing down, under its layers, the utensils, weapons, ornaments, and occasionally the bones and skulls of each succeeding generation. Could you find such a cavern, it is clear that you would be as favorably situated for studying the manners and customs of the very earliest occupants as of the latest; all that would be needed would be due care in removing one layer after another, and in examining what lay beneath, down to the bed-rock.
>
> No cavern will ever be found, it may be presumed, in which the relics of all generations have been thus conveniently kept for our inspection. But the case has been more nearly realized than one might suppose who had not given the matter consideration.
>
> Prehistoric time has been divided into four distinct epochs, to which names are given corresponding to the materials used for the manufacture of weapons and implements. The Paleolithic Period is the most ancient, including the time when man had only rough and uncouth flints for service and defense, along with awls and needles of bone. The Neolithic Period, also very remote, marked an improvement in the development of a purely stone age, the elaborate finish given to axes, arrow heads, cups and vases, polished by patient grinding, commanding admiration even now. The Bronze Period comes next, in which men had found that copper was malleable, and laying aside their flints, whether rough or polished, wrought swords, spears, shields, and ornaments of that metal and its alloys. The civilization of ancient Mexico and Peru shows what may be attained by a purely bronze age. The nobler metals have

always been scarce, and therefore were laid aside, except for adornment, when the Iron Period brought in the common and useful metal that has ever since been regarded as so indispensable in the arts, both of peace and war. The later iron period, of course, brings us down to the era of authentic history. And it should be remarked that all these periods really overlap each other, the dividing lines not being sharply marked. The barbaric hosts of Darius and Xerxes made use of stone arrows, as well as of superior kinds of weapons. The same is true of savage tribes of recent times. Dr. Arthur Mitchell, in a recent visit to the Hebrides, Shetland and the Orkeneys, found people who could even read and write, and yet were using, from choice, stone implements of various sorts, and some of whom dwelt in caves.

Whatever exceptions there may be to the classification just explained, it has found general favor among writers on archæology, and appears to be founded on characteristic distinctions. It is as though we should speak of America as a civilized nation, knowing that there are within our borders wild Indians and other human beings whose individual claims to culture would be disputed.

The point that now interests us is that under the stalagmitic flooring of caverns are found the unmistakable relics of man in all the prehistoric periods, by examining which we can learn facts about the race not to be ascertained otherwise.

That the primeval troglodytes were familiar with the genial warmth and useful energy of fire, appears from the ancient hearth-stones and quantities of charcoal and ashes. We do not know how they kindled their fires, nor how they cooked their food. These people lived by hunting and fishing, as is proved by their weapons and the broken and calcined bones accompanying their remains. They pursued animals of every size, great and small; but their main dependence was on the enormous herds of reindeer. They also fed on the bison, the musk-sheep, the ibex, the ox and the horse. There is no evidence that they had any domesticated animals. They are not supposed to have learned the art of spinning, nor the potter's trade; but the numerous bone awls and needles found show that they probably clad themselves in garments of skins sewed together with sinews. Bone harpoons, like those now used by the people of Terra del Fuego, were common, and proved the owners to be fishermen; and hundreds of seashells hint plainly of occasional voyages.

The Fossil Man was an artist. He had his hours of leisure when floods or storms shut him into his cave-dwelling, and he exercised his ingenuity in carving figures of the creatures he knew. Many specimens of his art have been found—older far than the most ancient Egyptian handiwork, and compared with which Grecian sculpture is a thing of yesterday. True, some of those prehistoric attempts at etching look very much like the pictures children draw on their slates and that need an interpreter. But others were done with a skillful hand and with sufficient clearness to enable us to form an idea of the object represented. The material used was of a durable nature, being usually tablets of horn or ivory, and more rarely a smooth stone. A pebble shows a tracing of the great cave bear; and a piece of schist, one of a reindeer fight. Cylinders, supposed to have been handles of some kind of weapon, display now the figure of an ox, and again of a reindeer, while a third shows the head of a horse or a bison. On the scapula of an ox there is a picture of a fishing scene, the creature harpooned looking "very like a whale." The man in this case is badly drawn, and, indeed, the rule seems to hold concerning all attempts by the cave artists to preserve their own features for modern inspection.

The most important, and also the best executed of all these etchings, is that representing the mammoth. It was found in 1864, in the rock hollow at La Madelaine, and correctly describes this greatest of mammals, judging from his perfectly preserved remains in the ice-fields of Siberia. How can we withhold our respect from the man who first fought the mammoth, and then had the skill to carve the figure of his foe on a tablet of ivory taken from its own tusk? What more could you ask of Nimrod himself?

While, as has been seen, the gentlemen of the French Association recognized their ancestors in those men of Vézère, others regard the latter as allied to the modern Esquimaux. The probability is that, on the invasion of Europe by the men with the polished flints, the older tribes were partly dispersed and partly absorbed, thus forming new ethnical groupings.

Description of Cavernous Regions

It is impossible to consider here all the cavernous regions of the Earth or to describe even one in detail, but two quotations (Hovey, 1882, pp. 64-65, 123-124) will serve to give an idea of the characteristics of these regions, on the surface and below the ground:

> The cavernous limestone of Kentucky covers an area of 8,000 square miles, and varies in thickness from 10 feet to 300 or 400, the average, perhaps, being about 175 feet. This rock shows few traces of dynamic disturbance, but has been carved by acidulated water, since the Miocene epoch, into numberless caverns.
>
> The absence of running streams is one of the striking features of the region, explained by the fact that nearly all the rivulets have long ago eaten their way through to drainage level, and re-appear as large springs feeding rivers of considerable size. It is said that one may, in certain directions, travel fifty miles without crossing running water. The voyager along such rivers as exist, will observe, at intervals, arches in the bluffs, whence the waters of subterranean streams emerge; and should he explore these openings, he would find them the entrances to caverns ascending by tiers toward the general surface of the country. And were he to make his way from stage to stage—a thing not often possible—he would at length come out into a valley shaped like an inverted cone, along whose sides grow bushes and trees, usually matted into a dense

thicket. These valleys are called "sink-holes," and they serve to drain the surface around them. These sink-holes are said to average 100 to the square mile; and, according to Shaler, the State Geologist, "there are at least 100,000 miles of open caverns beneath the surface of the carboniferous limestone in Kentucky."

The cave region of Indiana resembles, in general, that of Kentucky, and covers the same geological formations.

For 20 miles north of Madison, nearly every ravine has its rock-houses and water-swept chasms. Occasionally true caverns are found whose roof is the solid limestone of the Upper Silurian, while the excavation itself is in the softer rocks of the Lower. One of these is estimated to be a mile and a half long; though at a point about 1,000 yards from its entrance the roof has fallen in, and the obscure opening, by which access is gained to the ample chambers and winding passages beyond, might readily escape notice. The stream flowing out of this cave runs through the village of Hanover, and then turns capriciously towards the Wabash, from the very banks of the Ohio.

Some of the streams of the region, after receiving tributaries and increasing in volume, suddenly sink into the sand or leap down a gorge and disappear, as

"Alph, the sacred river, ran
Through caverns measureless to man,
Down to a sunless sea."

One such stream is significantly named the Lost River. It is in Orange county, where it sinks and rises five times before finally emerging a mile below Orangeville. These "rises" are generally marked by gulfs denoting the fall of superincumbent rocks; and at one of them a small boat has been put upon the stream, it having been found to be navigable for a long distance under ground. It is certainly remarkable to see a stream 45 feet wide rise quietly, as if from a great depth, at the bottom of a wild forest ravine. Should Lost River ever find another channel, the cave that would remain might equal in size any hitherto discovered.

The stream flowing from Hamer's Cave, in Lawrence county, turns a mill-wheel 22 feet in diameter. The water fills the floor of the archway so that a boat is needed to make an exploration. After proceeding thus, for perhaps three-quarters of a mile, we reach a place where the whole body of water rushes violently down a passage only 3 feet wide, and with a noisy uproar. Carrying the boat around this fall, we can go on, 300 feet further, to "the grand cascade," beyond which progress is difficult.

Donelson's Cave, in the same county, also discharges a large mill-stream from its wide and lofty mouth. A light canoe is of service in making explorations, although in many places the stream is shallow enough to be waded easily. "Within is a magnificent cascade, where the stream rushes and leaps down a narrow passage with such violence that the rumbling noise is heard at the entrance. This passway is known to extend through Dalton's Spring, three-fourths of a mile to E. S. E. Near the entrance a dry cave is seen opening to the east; directly opposite, a lofty corridor leads to the west, and in less than 100 feet enters a grand hall 12 feet high, 300 feet long, and 40 feet wide." The upper chambers are frequented by bats, and the soil is rich in niter, which supplied a powder mill that formerly stood in the vicinity. Both these caves contain eyeless fish, crawfish, and insects.

Effects of Caverns on Topography and Drainage

Caverns of this kind effect a marked change on the topography and drainage of the region they underlie. Rivers disappear underground, perhaps not to reappear until they reach the sea; cone-shaped sinks abound and, unless the rainfall is abundant, vegetation is scarce; the residual soil is washed away, and the exposed surface of the limestone is deeply furrowed by solution.

Some of these districts are relatively barren as in Yucatan, southern Asia Minor, and western Yugoslavia; others are well watered and fertile as in Kentucky and Tennessee. In any case the rain that falls is absorbed by the cavernous ground as speedily as by loose, wind blown sand and surface drainage is at a minimum. The whole process of erosion is controlled by solution and is therefore markedly different from that in other regions.

In order to understand this process we will assume a set of conditions as postulated by E. M. Sanders (1921, pp. 593-604) and follow the changes which he outlines as the cycle of erosion progresses. The conditions are: a thick, massive limestone covered by impermeable strata upon which a normal stream system has developed, and underlain by another impermeable bed lying some distance above sea level. This mass is exposed to a climate with such dry summers that vegetation is much restricted.

The youthful stage of this cycle is marked by the remnants of the surface drainage that developed on the strata above the limestone before they were worn off. As the limestone is uncovered and solution enlarges joint and bedding planes there follows a progressive loss of surface drainage. Rivers disappear beneath the ground, caverns develop, sinks are formed, and the exposed surface of the limestone becomes covered with deep narrow furrows, many of which are five or six feet deep and only a few inches wide.

Maturity is reached when the underground drainage is well established, extensive caverns are present, and sinks, uniting at their borders, have destroyed the former stream valleys. The whole mass of the limestone is now honeycombed by narrow channels and yawning hollows. When the underground streams reach and uncover part of the lower impervious stratum, maturity is passed. Valleys begin to form again at this lower level as the roofs of caverns collapse and the limestone is stripped off from the lower layer. Finally, in old age, only a few remnants of the limestone are left upon the beds that were formerly buried beneath its mass, and normal, subaerial stream courses are established again. In time no trace is left of the limestone or of the process by which it was carried away.

There are many districts where this process is actively at work to-day. Perhaps the most widespread lies in western Yugoslavia. This, the Illyrian karst, includes western Slovenia, Croatia, and Bosnia, the lands of Montenegro, Dalmatia, and

Herzegovina as well as the neighboring parts of Italy. D. A. Wray (1922, pp. 400-401) describes some of its features as follows:

> *Caverns*
>
> Owing to its extensive system of underground drainage, the Illyrian karst is celebrated for its caverns, the most famous of which are those of Adelsberg, 50 miles east of Trieste, which are over 6 miles in length. The major portions of the large grottoes at Adelsberg represent the former subterranean course of the Poik River, which at the present time follows a lower hidden course, which can be followed in a boat for more than a mile, mainly along major joints in the massive Cretaceous limestones. The overlying limestone at the surface is studded with innumerable circular pits, known as "ponors," which in wet seasons considerably augment the River Poik where it emerges as the River Unz at Planina. There are five main caverns at Adelsberg which of late years have attracted a great deal of attention from visitors, and for whose benefit they are now illuminated with electric light in the summer months. One of the most spacious, the "Franz-Joseph-Elizabeth" grotto, measures over 200 yards in length and breadth, and has a height of more than 100 yards. Its unusually large stalactites and stalagmites are of considerable interest.
>
> The caverns, which are so common a feature of the Dalmatian islands, have long been famed for their extreme beauty. Many occur about sea-level, and owe their charm to the deep-blue iridescent colour of the water, doubtless the result of their being wholly in massive dolomite or limestone. Among the more important maritime grottoes, those of the island of Lissa stand pre-eminent; while the limestone grotto of Busi, a rocky islet off Lissa, has long been noted. On the mainland to the east of Ragusa-Vecchia, and south of Ragusa, is the famous grotto of Esculapius.

Much of this area is a barren, stony waste and in some districts the "polje"—flat, elongated, steep-walled valleys—furnish the only arable land. Water is difficult to obtain, and the thin veneer of residual soil, the "terra rossa", occurs in isolated patches only. D. A. Wray points out that while the development of the karst has been going on for a long period, other factors unite to bring about the condition of that land today. He says (1922, pp. 407-408):

> In the preceding pages it has been shown that karst conditions have been developing ever since the Miocene uplift of this region; it is clear, however, that present-day climatic conditions have a powerful effect on the landscape, while other factors have contributed towards its accentuation within historic times. Judging from historical records, much of Illyria, which constituted the flourishing province of Liburnia in the Roman era, was comparatively thickly wooded with beech and conifers, and this condition would assist in the gradual accumulation of a thin veneer of "terra-rossa." Since that period the wood has been gradually removed, both by the Venetians to supply the innumerable piles on which their city is built, and also by them and the Ragusans to build their extensive fleets. This, coupled with the indiscriminate cutting of timber for every conceivable purpose, and the destruction of young shoots by the countless herds of goats reared in this region, have left much of it unprotected, so that in the hot dry summer the "terra-rossa" covering is carried away to produce the extensive sand-dunes seen to the north-east of Gospits, to the south of Koprivnitsa and elsewhere. In Montenegro the wood has been indiscriminately removed, both by the Montenegrins themselves and also by the Turks, partly to prevent ambush along their former northern frontier. Rainfall and wind have completed the work of destruction by removing the loose humus, producing a region of unrivalled barrenness. Districts like the Sinjavina Planina, which were known to be well-wooded and to contain numerous settlements less than 200 years ago, are to-day dreary stony wastes.
>
> The most powerful factor at the present day in the production of the bare surfaces is the dry and cold wind, known as

the "bora", which blows with extreme severity from the high uplands to the north of the Illyrian wastes throughout the winter months. Bosnia, which is little affected by the "bora", is consequently not so bare as regions nearer the coast and the majority of its uplands are thickly covered with deciduous forests. Herzegovina, on the other hand, the barren nature of which is proverbial, suffers considerably from its effects. The necessity for a close study of the karst and its geology was recognized many years ago by the former Austrian authorities. The shortage of water in many summers is acute, for in some cases a whole group of Herzegovinian or Dalmatian villages are dependent on a single well. Springs and wells are also so infrequent on the Montenegrin karst that the few that exist have become famed in national poetry, and have been the cause of endless dispute and bloodshed in the past. By the construction of storage reservoirs, and the irrigation of the floors of many of the poljes, the shortage of water has been met in part, and what were formerly inland marshes, unhealthy in summer time, have been converted into rich agricultural districts. Afforestation has also been systematically carried out along the Dalmatian coast for the last forty years, with the result that much of the country between Ragusa and Spljet is now covered with a luxuriant growth of beech and pine.

The peninsula of Yucatan lies well within the tropics, but differs from the neighboring lands in that most of it is extremely dry despite a fairly abundant rainfall. Leon J. Cole states this is due to the limestone that underlies it and into which the rain sinks rapidly. He says (1910, pp. 321, 323-324):

The Caverns and People of Northern Yucatan

The northern part of the Yucatan Peninsula, instead of having the luxuriant tropical vegetation often found in countries of low latitude, is in reality a great semi-arid plain. The forests, nowhere dense, dwindle away in parts to a stunted "brush" barely supported by the scanty soil which only partially covers the underlying limestone rock. It is, indeed, to the porous character of this rock and the absence of pronounced relief, rather than to a deficiency in the rainfall, that the aridity must be chiefly ascribed. The porous, fissured limestone rock is like a thirsty sponge which soaks in the water with only less avidity than the hot sands of a desert. Under these circumstances, it is of interest to note that, before the Discovery, this region supported probably the highest civilization of the western hemisphere, and that the conditions of human occupancy at the present time are not wholly unfavorable.

At San Ignacio, about half way between Merida and the coast, the general surface appears to be almost as flat and level as a floor; and here one may look for miles, with almost unobstructed view, across the enormous plantations of henequen, the plant which supplies the "sisal" fiber of commerce, and which constitutes one of the greatest sources of wealth in Yucatan. South of Merida, however, the dissection of the plain has progressed further, and the surface topography is much more irregular. On account of the porosity and fissured surface of the limestone that constitutes the country rock, the heavy rains of the wet season cut irregular channels or "arroyas," whose positions are dependent upon the local conditions; but nowhere are these of any great length or permanency. For it should be understood that nowhere in the whole northern half of this great peninsula are there rivers or permanent surface streams, with the exception of a few short ones on the eastern coast; and these, . . . were probably underground streams whose roofs have fallen in. But in certain parts of the country there are more or less permanent pools or "aguadas," and the water is also to be found in deep caverns and sink holes. Many of the latter are of a peculiar chimney-like structure, and are known as "cenotes."

These "cenotes" are formed when the roofs of the dome-shaped caverns collapse. Then the typical "cenote" with vertical walls changes slowly into an "aguada" with sloping sides and a pile of rubble in its bottom covered with standing water.

Cole describes two typical "cenotes" and the use to which one of them was put (1910, pp. 324-325):

> The two well-known cenotes at Chichen-Itza may be taken as examples of what we may consider as typical. . . . The larger of these is known as the Sacred or Sacrificial Cenote because of the fact that, according to legend and as has recently been confirmed by dredgings, it was a part of the Mayan religious ceremonies to cast into this deep pool human sacrifices who were to intercede with the gods of water for a plentiful supply of that much-needed element. This cenote is nearly circular in outline, with a diameter of 190 feet, while its walls, which are in places vertical, and locally overhanging, are 65 feet high from the level of the water to the general surface of the ground above. It is thus like a great circular shaft or stone quarry with a pool of water at the bottom.

These vertical, shaft-like holes are characteristic of the Yucatan karst even in the higher lands. In the low northern section they abound almost to the exclusion of the horizontal tunnels and caverns that are so marked a feature of the ordinary karst regions. Many of them extend far below sea level at the present time and the rare connecting channels are nearly all submerged. There is a strong flow of fresh water towards the sea which emerges in great springs under salt water locally known as "boiling springs."

The Region of the Causses

The reader may wonder at the character that can be imparted to a land merely by the presence of limestone beneath it. If he has travelled through south-central France, the "Causses" region, let him recall the contrast between the barren plateaus and the land that lies at their feet. Neither altitude, nor rainfall, nor sunshine can account for this—only the rock is different. Whether or not he has visited the region it will be well to read this vivid description (Baring-Gould, 1894, pp. 3-6):

The traveller from Clermont to Béziers and Narbonne, after having crossed that spider-thread viaduct of Garabit, ascends to a granite plateau of lakes and pools, of oozing springs and running streams. The pastures are perpetually grassy, in May starred with narcissus. They are roamed over by dun-colored oxen, and in summer are cropped by tens of thousands of lean sheep, driven to these ever green pastures from the parched plains of Provence.

The granite is very ancient and decomposed. The soil consists of crumbled elvan overlain with a little peat. Nevertheless, owing to the abundance of water, this mountain plateau laughs with verdure. The reason why it is not a torrid waste, but a garden and a lawn, is that the subjacent rock is *impervious*. All the rain that falls on the heights lodges there, the turf absorbs, the gravel retains it, and both yield up the moisture leisurely in springs. . . .

The train, after having crossed the granitic Alp, swings down the ravine of the brawling Crueize, and presently pulls up to draw breath and take in water at Marvéjols.

Here on the left is seen, standing above the town, a solitary peak of dry salmon-colored rock, on which grow no shrubs, nor does it sustain any grass,—a fang of bald rock rising out of gums of equally naked rubble. This is the northern sentinel of the Causses. It is called Le Truc, and is over 3,000 feet high.

The Causses consist of a barren region, which I propose to describe. This region, as its name implies, is of limestone (*calx*), and it is barren because the lime rock is—what the granite is not—pervious.

The rains that fall on the mountain heights are drunk in at once; not a drop runs over the lips of the causse. It is far too thirsty to spill any. Every particle is sucked in, and disappears at once. The drops thus absorbed run together, not, as elsewhere, on the surface, but within, in articulate threads of water, then rills, lastly rivers, in the bowels of the great plateau.

> I said one day to a peasant, "Truly you live on a fossil sponge."
>
> "Pardon," was his ready reply; "on a stone sieve. A sponge absorbs water and retains it; a sieve lets all through and remains dry."
>
> The Causses are veritable deserts: in winter, a Siberia; in summer, a Sahara; and this bleached, ghastly waste lies in, and occupies a large surface of, beautiful, smiling France. The Causses extend over a considerable area; they lean against the western flanks of the Cevennes, and extend south within sight of the blue Gulf of Lyons, and to the west within a hundred miles of the grey, windlashed Bay of Biscay. They cover a large portion of the departments of Lot, Lozère, Aveyron, Gard, and Hérault, and rise from 2400 feet to 3000 feet above the sea.

This same author (Baring-Gould, 1894, pp. 6-7) gives the following quotation from Onésime Reclus, which, while possibly exaggerating the desolateness of the Causses, draws a striking contrast:

> In descending, by goat-paths, from the plateau by the precipices that edge them, one is suddenly transported from parched wastes to pleasant pastures, from vast horizons vague in outline, and utterly sad in complexion, to joyous nooks of blended heaven and earth. Above, on that stone table, are wind, cold, nakedness, poverty, moroseness, hideousness,—a void, for few villages are found aloft; below, orchard land, warmth, gaiety, abundance.

The caverns that have developed in this region are famous because of the light they shed upon the habits of the men and animals who found shelter and protection there before the dawn of history. So the Causses have not always been shunned by man and beast. In much later times, in fact, the outcasts of the human race and the hunted fugitives from the "Reign of Terror" found asylum in these quiet recesses, perpetually dark, whose stillness is broken only by the dripping water that passes down from the wastes above.

Mechanical Work of Ground Water

The main work of ground water is the chemical work that has just been described. But it does mechanical work as well: when it adds its weight to that of a mass of rock or soil poised on a steep slope, it acts as a lubricant and helps the rock to slide downhill. Sometimes slow earth flows result. A famous case of such a flow is described by Blackwelder (1912, pp. 487-491) as follows:

The Gros Ventre Slide

Most settlers and others who have recently visited the mountains south of Yellowstone Park know "the Gros Ventre slide." Its wide reputation is due largely to the fact that for several years the landslide made communication between the upper and lower parts of the valley of the Gros Ventre River difficult and uncertain. Although the name which heads this paper is the one generally used in the vicinity, it is not quite satisfactory to the geologist, because it suggests the sudden plunge and immediate quiescence which attend landslides and avalanches in general. As the facts presented in these pages indicate, the term "earth-flow," or even "earth-glacier," would be more appropriate in this case.

The position of the slide may be found by consulting the southwest part of the Mount Leidy, Wyoming, topographic sheet, published by the United States Geological Survey. It occupies the valley of Lake Creek, one of the many small southern tributaries of the Gros Ventre River.

Geologic Conditions Affecting the Slide

In order to understand the phenomenon itself, it is necessary to know the geologic structure and topography of the locality. The Gros Ventre River has excavated its valley roughly parallel to the strike of a thick series of rocks which dip gently northward. Along the south side of the valley, therefore, the strata dip at angles of about 10 to 20 degrees away from the Gros Ventre Mountains and toward the river. Locally this monocline is gently fluted with small cross-folds, and one of these forms the east side of the slide. In this locality the prevailing rocks are soft upper Mesozoic shales with some beds of sandstone and a little limestone. They range in age from the Morrison and even Sundance (Jurassic) formations up to horizons equivalent to the Benton. Soft shale and clay predominate.

The edges of these argillaceous beds are upturned along the crest of a spur of the Gros Ventre Mountains, and in that situation readily become soaked with water from rains and from the melting of the snow in spring. At the lower edge of the slope the Gros Ventre River is actively widening and deepening its valley, and in so doing undermines the adjacent slope from time to time. These conditions together favor landslide action of one kind or another. What actually happened in the case of the Gros Ventre slide may now be considered.

History of the Slide

Several years ago, before the disturbance began, the small valley now occupied by the slide was bottomed with a hummocky sheet of old landslide material which originated before any of the present settlers came to the valley. In that respect it resembled many other tributary valleys in the vicinity. According to residents of the district, the slide first came into action in May, 1908. So far as I am able to learn, no one actually saw it begin; but it is believed by some that the initial movement was fairly rapid if not indeed precipitate. When first observed, the disturbance was manifested only at the head of the gulch, where large masses of the slippery Morrison and Sundance (Jurassic) clays had slumped down along the steeper slopes, overturning trees and leaving a general wreck. Either quickly or slowly, the impulse from this upper mass was then communicated to the old landslide debris farther down the valley, and that in turn began to press forward, bulge, and crack. The novel thing about this case is that the movement of at least the lower part was very slow and yet continuous, like that of a glacier.

A man who passed along the valley of the Gros Ventre River by the main road in the fall of 1908 said that the jumbled mass of earth, rock, overturned trees, and undergrowth could be plainly seen half a mile or more above the road at that time, and I infer from his description that it presented a steep outer slope not unlike that of a glacial moraine. At that stage the only sign of disturbance at the road consisted of a long crevasse on the eastern edge of what is now the slide, but that sufficed to show that the lower mass was already beginning to move. Day by day this large crack became wider and developed subsidiary fractures, but the only sign of movement visible to the bystander was the constant falling of small particles of dirt from the walls of the crack.

Whether or not motion continued during the winter of 1908-1909 I have not learned; but in the spring of 1909 the material in the lower part of the valley slowly pushed forward and its surface bulged into low irregular domes fretted with open crevasses, many of which were several feet wide. By its advance the glacier-like mass gradually obstructed the Gros Ventre River, which soon formed a lake more than a mile in length and several hundred yards in width. This still exists, but the rapid cutting down of the outlet has already (August, 1911) lowered the surface of the water about 10 feet.

So far as observed, the motion of the slide was not at any time rapid enough to be actually seen. The evidence of it, however, was plain enough. It was found impossible to keep the Forest Service telephone line in repair more than a few days, for the poles would slowly move down hill or be overturned and thus snap the wire. The wagon road soon became so hopelessly twisted and broken that it was almost impossible for wagons to follow it without capsizing, and it was no easy task to cross it even on a saddle horse. Attempts to repair the damage were almost futile, because in a few days the road would be rendered again impassable by folds of earth several yards in height or by gaping crevasses with vertical walls. In a short time the old road was completely destroyed, so that even traces of it are now hard to find. It thus became necessary for every one who attempted to cross the slide to pick out his own course, and not infrequently he was obliged to spend some hours with pick and shovel grading some of the worse places in order to render it possible to take a wagon over the slide at all.

According to members of the United States Forest Service, the slide did not move as one mass, but rather in sections; the disturbance began on the east side and manifested itself week by week at new places. Changes progressed most rapidly in the wet spring months and declined noticeably toward autumn. The slow but apparently incessant movement continued through the years 1908, 1909, and 1910, but in 1911 had practically ceased.

Importance of Earth-flows

Older earth-flows or landslides issue from most of the gulches along the south slope of the Gros Ventre Valley and have been seen at other points in adjacent valleys. At first glance they are easily mistaken for glacial moraines, and where both occur together, as below Dorwin's ranch on the Gros Ventre, only the most painstaking and critical study will serve to discriminate the two types of deposits.

In this region earth-flowage of the kind described is one of the most important processes by which the adjacent mountains are wasting away. It must be ranked with stream erosion, ordinary slumping and glacial work, as an important means of getting material from the higher slopes down into the bottoms of the valleys, where streams can continue the deportation. That it is of great importance here and in a few other localities, but negligible in most other mountain regions, I ascribe to the fact that the operation of the process depends on somewhat unusual conditions: very weak unctuous materials exposed along rather steep slopes, and especially on slopes in which the strata dip downward with the surface. It is well known that in most Rocky Mountain and other uplifts the very weak strata, such as predominate in the Jurassic and Cretaceous formations, have generally been planed off to lowlands, leaving only the firm sandstones, limestones, and still harder beds to form the mountain slopes. This is believed to explain the general absence of earth-flows from such ranges as the Wind River Mountains, the Bighorn Mountains, and many others of the Rocky Mountain chain.

A Violent Landslide

Not all landslides advance as slowly as the one just described. A mass of rock, poised on a steep slope, needs very little to send it plunging into the valley below. Disastrous avalanches occur in all high mountain ranges. They are frequently started by snow slipping off a steep slope, but avalanches of rock alone have caused appalling loss of life and property. In 1903 a part of the little coal mining town of Frank, Alberta, in the Front Range of the Canadian Rockies, was wiped out by a sudden slide of rock. The story is told by McConnell and Brock (1904, pp. 6-7) as follows:

Description of the Slide

At dawn, on April 29, 1903, a huge rock mass, nearly half a mile square and probably 400 to 500 feet thick in places, suddenly broke loose from the east face of Turtle mountain and precipitated itself with terrific violence into the valley beneath, overwhelming everything in its course. The great mass, urged forward by the momentum acquired in its descent, and broken into innumerable fragments, ploughed through the bed of Old Man river, and carrying both water and underlying sediments along with it, crossed the valley and hurled itself against and up the opposite terraced slopes to a height of 400 feet. Blocks of limestones and shale, mingled with mud, now cover the valley to a depth of from 3 to probably 150 feet, over an area of 1.03 square miles.

The number of people killed by the slide is not known exactly, but it is given at about 70. The property destroyed includes the tipple and plant at the mouth of the Canadian American Coal and Coke Company's mine, the company's barn and seven cottages at the east end of the town of Frank, half a dozen outlying houses, with some shacks and camps, besides a considerable number of horses and cattle and a couple of ranches. The track of the Crow's Nest Railway was hopelessly buried for a distance of nearly 7,000 feet and the lower mile of the Frank and Grassy Mountain Railway met a similar fate. The people occupying the houses in the track of the slide were all swept away with it and destroyed, with the exception of a few near the edge of the slide, who escaped in some almost miraculous way, which they themselves cannot explain.

The slide occurred about 4:10 a.m., at a time when most of the inhabitants of the valley were asleep and before full daylight. The statements of the few eye-witnesses throw little light on the character of the slide, but the following notes obtained from them are not without interest:—

Karl Cornelianson was awakened by the noise. He rushed to the door of his house, which looked out over the first terrace flat and the base of the second. His first thought was that there had been an explosion at the mine and his first look was in that direction. Seeing nothing there, he glanced round to the terrace flat in time to see the rock debris hurl itself against the slope of the second terrace, and its momentum spent, fall back to the lower level. His impression was that an explosion had taken place directly in front of him. The edge of the slide was about a quarter of a mile from his door.

Mr. McLean, who kept a boarding house in Frank, was already up. Hearing the noise, he rushed to the door in time to see the slide rush by only a few feet in front of him. The passage of the slide was so instantaneous that he thought an eruption had taken place directly in front of him.

A freight train was shunting on the mine siding at the time of the disaster. They had taken some cars of coal from the tipple at the mouth of the tunnel and were slowly backing up for another load, when the engineer heard the rocks breaking away from the mountain above. He immediately changed to full speed ahead and ran out of danger. The conductor saw the men at the tipple become alarmed and start to run, but they were overtaken by the slide and perished. Immediately after everything was shrouded in a cloud of dust.

Mr. Warrington, who was sleeping in one of the cottages destroyed, was awakened by a noise which he thought was caused by hail. He jumped out of bed and then realized that it was something more serious, but before he had time to become alarmed the house began to rock, and the next thing he was conscious of was finding himself in the lee of some rocks, forty feet from where the house had stood. His bed was some twenty feet farther on. His thigh was broken and he was otherwise injured by small fragments of debris being forced into his body. He pulled himself out with his arms, and was trying to work his way to some children, whose cries he heard, when the first rescue party arrived.

Water Witching

The practice of water witching has come down to us from ancient times. No one has found any scientific basis for it but there are many men today who answer all objections by the statement that "it works". Voluminous writings on the subject exist, but the modern scientific attitude concerning it has been summed up very briefly by O. E. Meinzer in his introduction to a paper by W. J. Ellis (1917, pp. 5-6):

> The use of a forked twig, or so-called divining rod, in locating minerals, finding hidden treasure, or detecting criminals is a curious superstition that has been a subject of discussion since the middle of the sixteenth century and still has a strong hold on the popular mind, even in this country, . . .
>
> It is doubtful whether so much investigation and discussion

PLATE XIII

National Geographic Society

ENTRANCE TO CARLSBAD CAVERN, NEW MEXICO

An archway in a hillside leading down to one of the largest and most beautiful of all caverns.

PLATE XIV

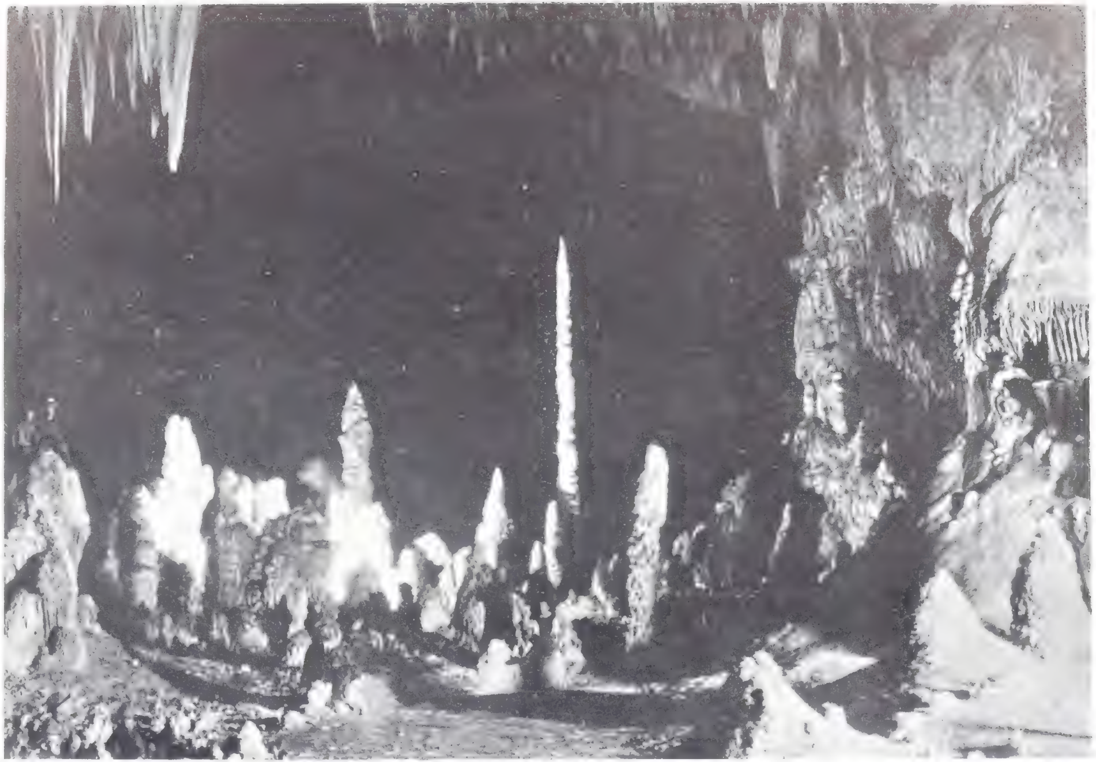


Photo R. V. Davis

A ROOM IN CARLSBAD CAVERN, NEW MEXICO

Stalagmites rise as slender spires from the cavern floor.

have been bestowed on any other subject with such absolute lack of positive results. It is difficult to see how for practical purposes the entire matter could be more thoroughly discredited, and it should be obvious to everyone that further tests by the United States Geological Survey of this so-called "witching" for water, oil, or other minerals would be a misuse of public funds.

A large number of more complicated devices for locating water or other minerals are closely related to the forked twig. A favorite trick for appealing to uneducated persons and yet making specific disproof impossible is to give as the working principle of such a device some newly discovered and vaguely understood phenomenon, as, for example, radioactivity. Many such devices have been in existence since the seventeenth century, and almost without exception the claims that are made for them are very great. If any genuine instrument were invented its merits would no doubt in time become well recognized, as have those of other real inventions. The magnetic needle used in detecting iron ore, is, of course, not included in this category of spurious instruments.

It is by no means true that all persons using a forked twig or some other device for locating water or other mineral are intentional deceivers. Some of them are doubtless men of good character and benevolent intentions. However, as anything that can be deeply veiled in mystery affords a good opportunity for swindlers, there can be no reasonable doubt that many of the large group of professional finders of water, oil, or other minerals who take pay for the "services" or for the sale of their "instruments" are deliberately defrauding the people, and that the total amount of money they obtain is large.

To all inquirers the United States Geological Survey therefore gives the advice not to expend any money for the services of any "water witch" or for the use or purchase of any machine or instrument devised for locating underground water or other minerals.

BIBLIOGRAPHY

Chapter V—Ground Water

S. Baring-Gould, *The Deserts of Southern France.* London: Methuen & Company, 1894, vol. 1, pp. 3-6, 6-7.

Eliot Blackwelder, *The Gros Ventre Slide, an Active Earth Flow.* Bulletin of the Geological Society of America, vol. 23, 1912, pp. 487-491.

T. C. Chamberlin, *The Requisite and Qualifying Conditions of Artesian Wells.* U. S. Geological Survey, 5th Annual Report, 1885, pp. 132-168.

Leon J. Cole, *The Caverns and People of Northern Yucatan.* Bulletin of the American Geographical Society, vol. 42, 1910, pp. 321, 323-324, 324-325.

Arthur J. Ellis: *The Divining Rod.* U. S. Geological Survey Water-supply Paper 416, 1917, Introductory Note by O. E. Meinzer, pp. 5-6.

H. E. Gregory, *Military Geology and Topography.* Yale University Press, 1918, pp. 141-143.

H. C. Hovey, *Celebrated American Caverns.* Cincinnati: Robert Clarke & Company, 1882, pp. 18-21, 37-39, 41-42, 64-65, 123-124.

Eliot Lord, *Comstock Mining and Miners.* U. S. Geological Survey, Monograph 4, 1883, pp. 1-2.

R. G. McConnell and R. W. Brock, *Report on the Great Landslide at Frank, Alberta.* Canada Department of the Interior, Annual Report for 1902-1903, part VIII, 1904, pp. 6-7.

W. H. Norton, *Artesian Wells of Iowa.* Iowa Geological Survey, vol. 6, 1897, pp. 350-352.

E. M. Sanders, *The Cycle of Erosion in a Karst Region (After Cvijić).* Geographical Review, vol. 11, 1921, pp. 593-604.

C. H. Shamel, *The American Law Relating to Minerals.* The School of Mines Quarterly, vol. 27, 1905, p. 18.

D. A. Wray, *The Karstlands of Western Yugoslavia.* Geological Magazine, vol. 59, 1922, pp. 400-401, 407-408.

CHAPTER VI

LAKES AND SWAMPS

Lake Bonneville

> FROM this gradual change of lakes into rivers, it follows that a lake is but a temporary and accidental condition of a river, which is every day approaching to its termination; and the truth of this is attested, not only by the lakes that have existed, but also by those that continue to exist.

This statement (Playfair, 1802, p. 357) is true equally of the great lakes of the world and of little puddles of water left after a hard rain. The observer who can believe that the horizontal line around the rim of a dry puddle is a "waterline," left there when the puddle was full, can believe with equal ease—and with equal certainty—that the line around the rim of the Wasatch Mountains and the other ranges that enclose the basin of the Great Salt Lake, is also a waterline, and that it therefore marks the position of a former puddle of gigantic size. The terraces high up on the mountain flanks were correctly interpreted by the early Government survey parties. G. K. Gilbert devoted much time to their study and later wrote a lengthy account of "Lake Bonneville", as this ancient ancestor of Great Salt Lake was called. This account was published as Monograph I of the U. S. Geological Survey, and is regarded by geologists as a masterpiece of interpretation and exposition. A part of Gilbert's discussion (Gilbert, 1880, p. 131; 1882, pp. 173-174) is reproduced here:

> The Great Salt Lake Desert and a congeries of valleys connected with it were filled with water at a period so recent that the vestiges of the flood are little impaired at the present time. The sea cliffs that were covered by the dash of the ancient waves are sea cliffs still, though they stand a thousand feet above the present level of Great Salt Lake. The bars and

beaches of sand and gravel that were built by the ancient currents are furrowed here and there by the rains that have since fallen on them, but they are furrowed only, and not destroyed; and the imagination is not strained to fill the gaps and restore their full contours. The fine silt that settled quietly in the deeper waters still forms the floors of the valleys. To the geologist accustomed to speak familiarly of millions of years, it is the veriest yesterday when all these things were wrought; nor can any one who stands on the quartzite shingle of one of the old beaches, and contemplates the rounded pebbles, gleaming with the self-same polish they received when the surf laid over them, fail to be impressed by the freshness of the record.

There is a topography of the land and a topography of the water. The forms of the land are sculptured by the beating of the rain and by the flow of rills, and creeks, and rivers, and they have peculiar characters accordant with their origin. The forms of the beds of lakes and oceans, and especially the forms of shores, are sculptured by the sway of waves and currents, and are distinguished by characters equally peculiar. All the hills and mountains above the shore line of Lake Bonneville bear witness of the play of subaerial agents, while below that line the slopes betray their subaqueous shaping. There is a trenchant line between them, and their peculiarities are beautifully contrasted. A careful inspection, however, shows that subaqueous characters are superimposed on subaerial characters. The forms belonging to the dry land are continued down past the shore line, and the sculpture of the lake has been superficially impressed on them without entirely obliterating them. It is thus made evident that before the epoch of the lake, the land it covered was dry, just as it is now. The lake had a beginning as well as an end. It came, it lingered long enough to make an unmistakable record, and then it departed as it came.

A lake without outlet cannot maintain a constant level, because its quantity of water depends upon the relation of the rainfall to the superficial evaporation, and these elements of climate are notoriously variable. A series of moist seasons increases its contents and causes its margin to advance upon the land, while a succession of dry seasons produces the reverse effect and makes it shrink from its borders. With a lake having a discharge the case is different, for every increase or diminution of supply, by slightly raising or lowering the surface, increases or diminishes the discharge, and thus a practical equilibrium is maintained. It can therefore rarely happen that the waters of a lake without outlet are held at one level for the time necessary to produce a strongly marked, individual shoreline, and for this reason it was early surmised that Lake Bonneville found an escape for its surplus waters at the times of the formation of the Bonneville and Provo shorelines. Search was therefore made for a point of outlet, and eventually it was discovered at the northern extremity of Cache Valley. The sill over which the water at first discharged was of soft material which yielded easily to the wear of the running water and permitted the lake level to be rapidly lowered by the mere corrasion of the outflowing stream, but eventually a reef of limestone was reached by which the erosion was checked and the lake was held at a nearly constant level until its outflow was finally stopped by climatic changes which diminished the water supply. The level of the soft sill first crossed by the outflowing water is the level of the Bonneville shoreline at the nearest point where it is visible; the level of the limestone sill is coincident with that of the Provo shoreline; and the discovery of these facts correlated in a satisfactory manner the history of outflow with the history of the most conspicuous shorelines. As will presently appear, it was the work of the past summer to complement this knowledge by obtaining an interpretation of the intermediate shorelines.

The detritus the waves bear away from one part of a coast is not all accumulated in the adjacent embankments; only the sand and gravel are there collected, and the finer matter, which is capable of being held in suspension by the water for a longer time, is borne to a greater distance from the shore and finally settles to the bottom in the form of mud. Moreover, the streams which flow from the land to a lake bring with them each its quota of mud too fine to subside quickly, and this, too, is deposited in the depths remote from the shore. Thus the whole surface of every lake bottom becomes coated with a fine mud derived from the demolition of the surrounding land by rains and rivers and by waves.

Nor is this all: the wear of the rains and even the wear of the waves is not limited to abrasion, but includes also solution. All rock material is to some extent soluble by water, and every river carries to the sea or lake into which it empties not merely gravel and sand and silt, which are visible to the eye as impurities, but various minerals so intimately combined that the eye cannot detect them, although they are readily discovered by chemical tests. A lake which receives the water of a river or rivers, and is itself drained by an outflowing river, catches in its sediments the mechanical detritus only, which settles to the bottom where the current is checked, and permits all or the greater part of the chemical contents of the water to escape; but a lake with no outlet accumulates the entire mineral contents of the tributary streams, storing the mechanical detritus as a sediment, and the dissolved minerals either as a precipitate or else, by the aid of animal life, in some form of organic debris. The record of a lake is therefore written, not only by its wave-wrought shorelines, but by its mechanical and chemical sediments, and the investigation of Lake Bonneville necessarily included a study of the beds deposited upon its bottom.

Colorado River and the Salton Basin

Many accounts of the origin of the Salton Basin in extreme southern California have been written. For many years it has been known that the so-called Imperial Valley is the former head of the Gulf of California, cut off from the rest of the Gulf by the gradual outward building of the delta of Colorado River, and left thus as a great bowl whose bottom is nearly three hundred feet below the level of the sea. Technical accounts and reports exist, but none tells the story more entertainingly, and none more clearly, than that of John C. Van Dyke (1901, pp. 44-53):

> In the ancient days when the shore of the Pacific was young, when the white sierras had only recently been heaved upward and the desert itself was in a formative stage, the ocean reached much farther inland than at the present time. It pushed through many a pass and flooded many a depression in the sands, as its wave-marks upon granite bases and its numerous beaches still bear witness. In those days that portion of the Colorado Desert known as the Salton Basin did not exist. The Gulf of California extended as far north as the San Bernardino Range and as far west as the Pass of San Gorgonio. Its waters stood deep where now lies the road-bed of the Southern Pacific Railway, and all the country from Indio almost to the Colorado River was a blue sea. The Bowl was full. No one knew if it had a bottom or imagined that it would ever be emptied of water and given over to the drifting sands.
>
> No doubt the tenure of the sea in this Salton Basin was of long duration. The sand-dunes still standing along the northern shore—fifty feet high and shining like hills of chalk—were not made in a month; nor was the long shelving beach beneath them—still covered with sea-shells and pebbles and looking as though washed by the waves only yesterday—formed in a day. Both dunes and beach are plainly visible winding across the desert for many miles. The southwestern shore, stretching under a spur of the Coast Range, shows the same formation in its beach-line. The old bays and lagoons that led inland from the sea, the river-beds that brought down the surface waters from the mountains, the inlets and natural harbors are all in place. Some of them are drifted half full of sand, but they have not lost their identity. And out in the sea-bed still stand masses of cellular rock, honeycombed and water-worn (and now for many years wind-worn), showing the places where once rose the reefs of the ancient sea.
>
> These are the only records that tell of the sea's occupation.

The Indians have no tradition about it. Yet when the sea was there the Indian tribes were there also. Along the bases of the San Bernardino and San Jacinto Ranges there are indications of cave-dwellings, rock-built squares that doubtless were fortified camps, heaps of stone that might have been burial-mounds. Everywhere along the ancient shores and beaches you pick up pieces of pottery, broken ollas, stone pestels and mortars, axe-heads, obsidian arrow-heads, flint spear-points, agate beads. There is not the slightest doubt that the shores were inhabited. It was a warm nook, accessible to the mountains and the Pacific; in fact, just the place where tribes would naturally gather. Branches of the Yuma Indians, like the Cocopas, overran all this country when the Padres first crossed the desert; and it was probably their forefathers who lived by the shores of this Upper Gulf. No doubt they were fishermen, traders and fighters, like their modern representatives on Tiburon Island; and no doubt they fished and fought and were happy by the shores of the mountain-locked sea.

But there came a time when there was a disturbance of the existing conditions in the Upper Gulf. Century after century the Colorado River had been carrying down to the sea its burden of sedimental sand and silt. It had been entering the Gulf far down on the eastern side at an acute angle. Gradually its deposits had been building up, banking up; and gradually the river had been pushing them out and across the Gulf in a southwesterly direction. Finally there was formed a delta dam stretching from shore to shore. The tides no longer brought water up and around the bases of the big mountains. Communication with the sea was cut off and what was once the top of the Gulf changed into an inland lake. It now had no water supply from below, it lay under a burning sun, and day by day evaporation carried it away.

No one knows how many days, how many years, elapsed before the decrease of the water became noticeable. Doubtless the lake shrank away slowly from the white face of the sand-dunes and the red walls of the mountains. The river-mouths that opened into the lake narrowed themselves to small stream-beds. The shelving beaches where the waves had fallen lazily year after year, pushing themselves over the sand in beautiful water-mirrors, shone bare and dry in the sunlight. The ragged reefs, over which the chop sea had tumbled and tossed so long, lifted their black hulks out of the water and with their hosts of barnacles and sea-life became a part of the land.

The waters of the great inland lake fell perhaps a hundred feet and then they made a pause. The exposed shores dried out. They baked hard in the sun, and were slowly ground down to sand and powdered silt by the action of the winds. The waters made a long pause. They were receiving reinforcements from some source. Possibly there was more rainfall in those days than now, and the streams entering the lake from the mountains were much larger. Again there may have been underground springs. There are flowing wells to-day in this old sea-bed—wells that cast up water salter than the sea itself. No one knows their fountain-head. Perhaps by underground channels the water creeps through from the Gulf, or comes from mountain reservoirs and turns saline by passing through beds of salt. These are the might-bes; but it is far more probable that the Colorado River at high water had made a breach of some kind in the dam of its own construction and had poured overflow water into the lake by way of a dry channel called the New River. The bed of this river runs northward from below the boundary-line of Lower California; and in 1893, during a rise in the Colorado, the waters rushed in and flooded the whole of what is called the Salton Basin. When the Colorado receded, the basin soon dried out again.

It was undoubtedly some accident of this kind that called the halt in the original recession. During the interim the lake had time to form new shores where the waves pounded and washed on the gravel as before until miles upon miles of new beach—pebbled, shelled, and sloping downward with great uniformity—came into existence. This secondary beach is intact to-day and looks precisely like the primary except that it is not quite so large. Across the basin, along the southern mountains, the second water-tracery is almost as apparent as the first. The rocks are eaten in long lines by wave-action, and are honeycombed by the ceaseless energies of the zoöphite.

Nor was the change in beach and rock alone. New bays and harbors were cut out from where the sea had been, new river-channels were opened down to the shrunken lake, new lagoons were spread over the flat places. Nature evidently made a great effort to repair the damage and adapt the lake to its new conditions. And the Indians, too, accepted the change. There are many indications in broken pottery, arrow-heads, and mortars that the aboriginal tribes moved down to the new beach and built wickiups by the diminished waters. And the old fishing-foraging-fighting life was probably resumed.

Then once more the waters went down, down, down. Step by step they receded until the secondary beach was left a hundred feet above the water level. Again there was a pause. Again new beaches were beaten into shape by the waves, new bays were opened, new arroyos cut through from above. The whole process of shore-making—the fitting of the land to the shrunken proportions of the lake—was gone through with for the third time; while the water supply from the river or elsewhere was maintained in decreased volume but with some steadiness of flow. Possibly the third halt of the receding water was not for a great length of time. The tertiary beach is not so large as its predecessors. There never was any strong wave action upon it, its pebbles are few, its faults and breaks are many. The water supply was failing, and finally it ceased altogether.

What fate for a lake in the desert receiving no supplies from river or sea—what fate save annihilation? The hot breath of wind blew across the cramped water and whipped its surface into little waves; and as each tiny point of spray rose on the crest and was lifted into the air the fiery sunbeam caught it, and in a twinkling had evaporated and carried it upward. Day by day this process went on over the whole surface until there was no more sea. The hollow reefs rose high and dark above the bed, the flat shoals of silt lifted out of the ooze, and down in the lowest pools there was the rush and plunge of monster tortuabas, sharks and porpoises, caught as it were in a net and vainly struggling to get out. How strange must have seemed that landscape when the low ridges were shining with the slime of the sea, when the beds were strewn with *algæ,* sponges, and coral, and the shores were whitening with salt! How strange, indeed, must have been the first sight of the Bottom of the Bowl!

But the sun never relaxed its fierce heat nor the wind its hot breath. They scorched and burned the silt of the sea-bed until it baked and cracked into blocks. Then began the wear of the winds upon the broken edges until the blocks were reduced to dry fine powder. Finally the desert came in. Drifts upon drifts of sand blown through the valleys settled in the empty basin; gravel and bowlder-wash came down from the mountains; the grease-wood, the salt-bush, and the so-called pepper-grass sprang up in isolated spots. Slowly the desert fastened itself upon the basin. Its heat became too intense to allow the falling rain to reach the earth, its surface was too salt and alkaline to allow of much vegetation, it could support neither animal nor bird life; it became more deserted than the desert itself.

And thus it remains to this day.[1] When you are in the bottom of it you are nearly three hundred feet below the level of the sea. Circling about you to the north, south, and west are sierras, some of them over ten thousand feet in height. These form the Rim of the Bowl. And off to the southwest there is a side broken out of the Bowl through which you can pass to the river and the Gulf. The basin is perhaps the hottest place to be found anywhere on the American deserts. And it is also the most forsaken. The bottom itself is, for the great part of it, as flat as a table. It looks like a great plain leading up and out to the horizon—a plain that has been ploughed and rolled smooth. The soil is drifted silt—the deposits made by the washings from the mountains—and is almost as fine as flour.

---

[1] This account was written prior to 1901. In 1906 and 1907 the Colorado broke its banks, the overflow once more filled the "Bowl" with water, and the present Salton Sea came into being. This lake is slowly disappearing by evaporation; each year sees its shoreline a little farther below sea level.—Ed. Note.

The Gros Ventre Landslide Lake

The sudden appearance of certain kinds of lakes, their comparatively brief existence, and their equally sudden disappearance, is well illustrated by the story of the Gros Ventre landslide in Wyoming and of the lake to which it gave rise. The account (Alden, 1928) given here is technical, but the facts speak well for themselves:

> A great landslide occurred on June 23, 1925, in the valley of Gros Ventre River, about 35 miles south of Yellowstone National Park. . . .
>
> Heavy rains and melting snow in the Gros Ventre Mountains had saturated clay layers in the Carboniferous strata, which dip toward the valley at angles of 18° to 21°, consequently an enormous mass of rock at the end of the north spur of Sheep Mountain became loosened and, on the afternoon of June 23, slid suddenly down into the valley. Within a few minutes this mass of debris—estimated as 50,000,000 cu. yd.—carrying on its surface a dense pine forest, rushed across the valley, piled up about 350 ft. high against the cliffs of red sandstone on the north and partly slumped back and spread so as to form a dam 225 to 250 ft. high above the lower toe of the dump. . . . The river, which was in flood, was completely blocked and rapidly filled the basin behind the dam, so that within 18 hrs. a ranch house standing 60 ft. above the river was floated off its foundation and in about three weeks the lake reached a depth of about 200 ft. at the back of the dam, an average width of about ½ mile, a length of about 4 miles, and an estimated area of about 11,000 acres. . . .
>
> Soon after the slide, water began seeping through the dam. This took care of the inflow, which decreased as the summer came on. . . .

There was considerable speculation by engineers and others as to what would occur when the snow melted in the spring of 1926. It happened that there was a light snowfall in the Gros Ventre Mountains in the winter of 1925-26, so no spring flood occurred, and conditions remained practically unchanged. . . .

The prediction of some engineers, and the fact that there was no break in the dam for nearly two years after the slide occurred, had given rise to a feeling of security and a rather general belief that the dam would hold. In the winter of 1926-27 heavy snows fell in the Gros Ventre Mountains and a period of rapid melting, together with rain, in May, 1927, caused a rapid rise of the lake, which, on the morning of May 18, overtopped the lowest part of the dam and caused a disastrous flood. In July, 1927, in company with my assistant, Edward F. Richards, I revisited the place to see the effects of the flood and the condition of the dam and lake. From the forest ranger, C. E. Dibble, and other residents of the village of Kelly, I obtained information as to what occurred.

We found that the outflow had cut a channel nearly 100 yd. wide and about 100 ft. deep beneath the crest of the dam near its down-stream face. The channel had a rather steep gradient and the head of the outlet was considerably back of the highest part of the dam, where a shallow, but a swift stream was flowing over the rocky debris. Measurement with a hand level showed the lake surface to be about 60 ft. below the high-water mark, so that there was yet probably a maximum depth of nearly 150 ft. of water in the lake.

In 1925, Herman Stabler, of the Geological Survey, estimated that, with the basin filled to the point of overflow, there would be 164,000 acre-feet impounded and that the cutting of a channel only 25 ft. deep would release about a quarter of this great amount of water, or 48,000 acre-feet. It was then predicted that sudden release of such a flood could scarcely result otherwise than disastrously. The dam did not fail as a whole, but the lake was lowered more than 50 ft. in a very short time, and disaster resulted.

The river had been slowly rising during the morning of May 18 at the village of Kelly, about 4 miles below the dam, and efforts were being made to prevent the highway bridge from being washed out. The stream had not overflowed its 10 to 15-ft. banks there up to 10 a.m. The appearance of some ranch utensils in the stream, however, warned Mr. Dibble that something was wrong at the dam. Rushing over the hills in his automobile, on the road leading up the valley, he witnessed the destruction of the buildings at Woodward's ranch about a mile below the dam and out of sight of it. He then sped back to the village and messages were sent down Gros Ventre and Snake River valleys to warn the inhabitants of the approaching flood. It is reported that about 11 a.m. there suddenly came from the mouth of the gorge above Kelly a great rush of water described as a wave 15 ft. or more in height, which caught some of the villagers as they were trying to save some of their effects. All the buildings were swept away with the rush excepting the schoolhouse and a small church and near-by cottage on a little higher level at the north edge of the village. . . .

In 1925, Kelly had a population of 60 or 70 people, of whom a few were drowned. Besides the destruction of the buildings and their contents in this village, several ranches on Gros Ventre and on Snake River were more or less damaged. Six or seven persons were drowned, some had very narrow escapes, bridges were washed out and effects of the flood were felt as far down Snake River as Idaho Falls, Idaho. It appears that there was time after the warning was given for all persons to have escaped with their lives if they had not stopped to save any of their effects. As is usually the case, however, some apparently did not appreciate the necessity for such haste. It is reported that water began to flow over the dam in three places on the afternoon before, but it does not appear that any definite watch was maintained at the dam even after flood conditions began to develop.

That which is of most interest to geologists and engineers is what actually happened at the dam. . . .

. . . Evidently such a jumble of loose porous material as composes the upper part of the dump would not form a permanent dam capable of withstanding overflow without controlling gates and adequate spillways. No trees or logs were seen buried in the rock debris. Evidently the forest trees rode down on top of the slide and were not mixed into the debris very much by rolling over. They form an almost impassable tangle of criss-crossed trees, some of them still alive, on top of the dam.

Apparently no person saw just what actually took place at the dam, but the composition of the upper part of the dam, as shown in this view, may explain why the main flood came so suddenly and with such great volume. Probably seepage increased rapidly as the lake rose and this tended to undermine at the same time as overflow at the lowest point cut the initial channel. There was an enormous quantity of water in the upper 50 ft. of the impounded body. Rapid deepening of the trench across the crest must have caused rapid slumping at the sides and the loose material must have at once been swept out of the way, opening a broad outlet toward which the enormous body of water started moving with rapidly increasing velocity. Repeated slumpings of the sides may have caused the reported succession of wavelike crests of the flood. Driftwood was found 10 to 14 ft. above the ground in trees on the flat below Kelly, so that there was a considerable depth of water, though it is said to have spread out to a maximum width of about ¾ mile within a mile below the mouth of the gorge. From an instrumental survey made by L. C. Bishop, it has been estimated that there was in the upper 50 ft. of the lake body nearly 43,000 acre-feet of water, and apparently all of this went out. By 4 p.m. the flood had passed Kelly and the stream had receded within its banks.

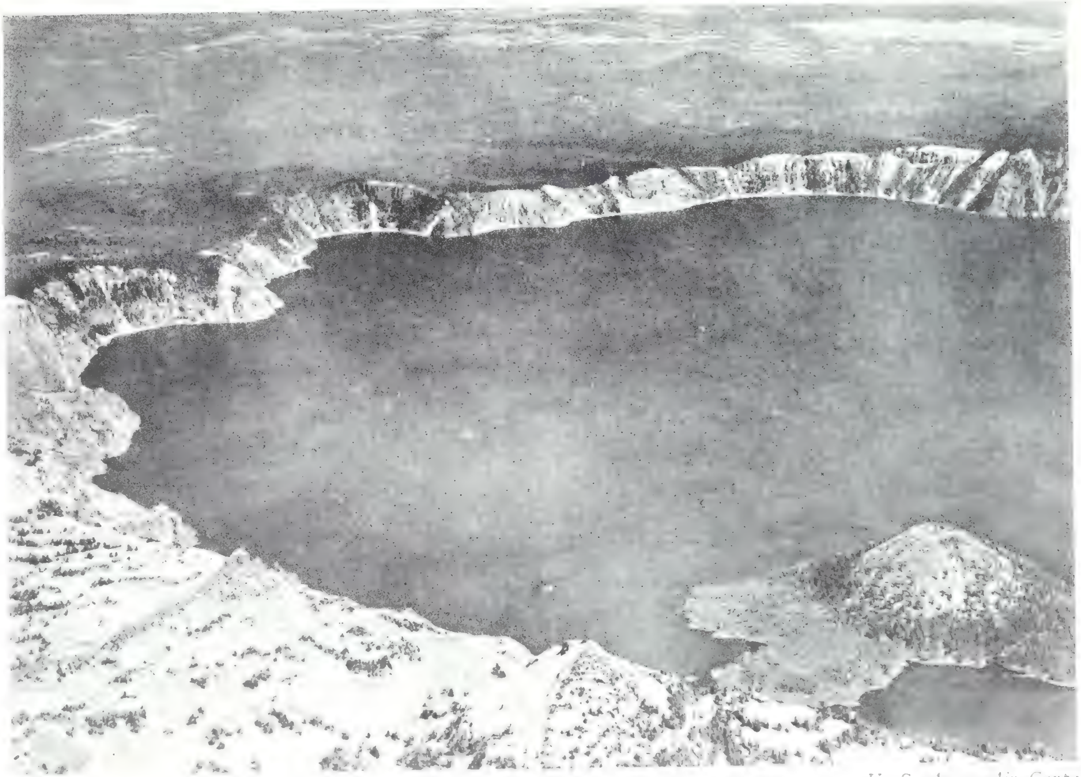
So great is the width of the dam ¼ mile or more from front to back below the high-water level that after trenching the first 50 ft. the amount of material to be moved was enormously greater and the rate of deepening became very much slower. With the lowering of the lake level the sill of the outlet thus moved gradually back while the channel below the crest of the dam was further deepened another 40 ft. The lake was lowered only about 60 ft. before the rate of cutting became so slow as to end the flood.

Completed melting of the snow and cessation of rainfall also soon reduced the inflow so that on July 5, 1927, the lake had lowered only about 2 ft. farther below a fairly definite water mark. I have no information as to conditions since that date. Probably the lake slowly lowered through the summer of 1927 and through the past winter as the outlet channel deepened.

There was still an enormous amount of water impounded in July, 1927, for the lake extended 3 or 4 miles up the valley, nearly as far as before. It probably yet had a maximum depth of 100 ft. or more after the flood, for the tops of tall trees were emerging only near the borders of the lake.

What will happen in case there is another period of rapid melting of heavy snows in the mountains, together with much rainfall? Of course, one cannot say definitely, but certainly the danger of such a flood as that of May, 1927, is greatly reduced. The outlet now provided may be deepened and broadened somewhat, but I see no reason to expect anything more than a normal high-water stage in the river below the dam. It may be that further deepening of the outlet may start renewed sliding on the south side of the valley. If this does not occur suddenly, it may simply retard the outflow by gradually encroaching on the stream, as has occurred in the case of an older slide about 15 miles farther up the valley. It would not, however, seem advisable to rebuild the village of Kelly on the same site on the low flat terrace directly below the mouth of the gorge.

PLATE XV

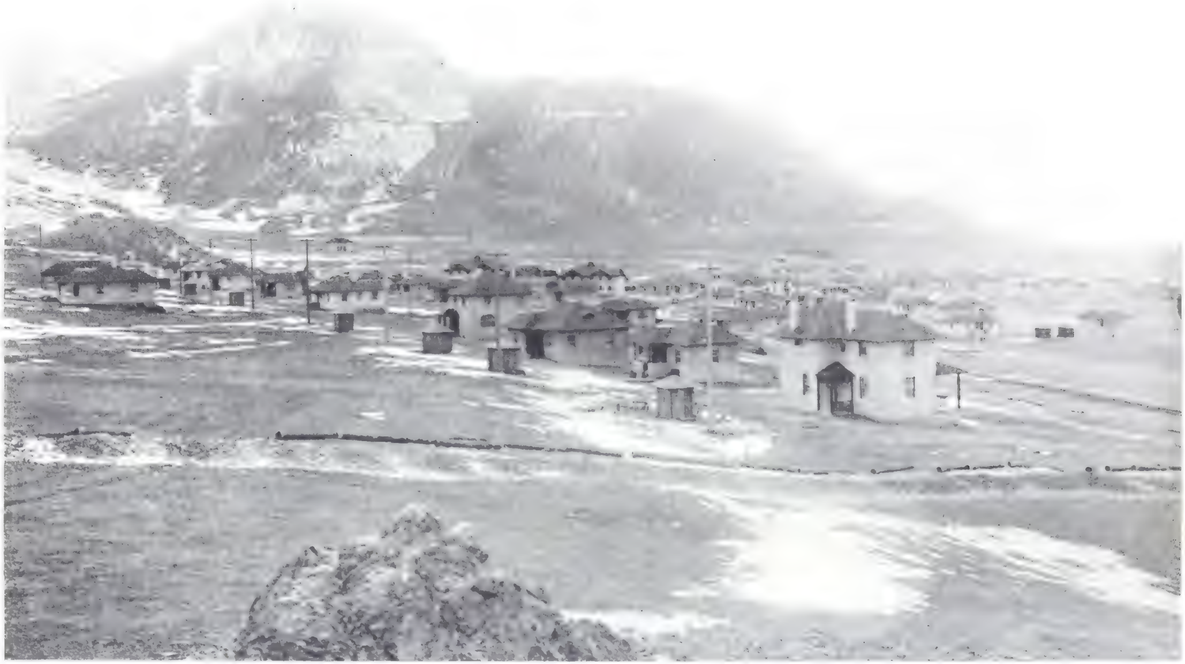


U. S. Army Air Corps

CRATER LAKE FROM THE AIR

A lake in the crater of a volcanic cone in Oregon, with an island made of a small inner cone.

PLATE XVI



TERRACES OF AN ANCIENT LAKE

Three former shorelines of old Lake Bonneville contouring the Oquirrh Range, at the southern end of the present Great Salt Lake, Utah.

The Preservation of Organic Matter in Swamps

Swamps are so closely allied to lakes that many basins contain lakes during one part of the year, and swamps during another. The chief geologic importance of swamps lies in the fact that they usually contain bacterial products that prevent decay; hence animal and vegetable matter is frequently preserved in bog waters. To this fact principally we owe our supply of coal. The preservation of organic matter in this way is illustrated by a somewhat gruesome account given in Bakewell's *Geology*, published early in the nineteenth century. It is altogether probable that the preservation was less perfect than the account (Bakewell, 1839, p. 393) indicates, because stories of this kind commonly are exaggerated. However, the fact of preservation appears to be well authenticated.

In the *Philosophical Transactions*, 1734, there is a letter from Dr. Balguy, giving an account of the preservation of two human bodies in peat for fifty-nine years. On January 14, 1675, a farmer and his maid servant were crossing the peat moors above Hope, near Castleton, in Derbyshire; they were overtaken by a great fall of snow, and both perished: their bodies were not found until the 3rd of May, in the same year; and being then offensive, the coroner ordered them to be buried on the spot in the peat. They lay undisturbed twenty-eight years and nine months, when the curiosity of some countrymen induced them to open their graves. The bodies appeared quite fresh, the skin was fair and of its natural color, and the flesh as soft as that of persons newly dead. They were afterwards frequently exposed as curiosities until in the year 1716, when they were buried by order of the man's descendants. At that time, Dr. Bourne, of Chesterfield, who examined the bodies, says the man was perfect, his beard was strong, the hair of his head was short, and his skin hard and of a tanned leather color, like the liquor he was laying in. The body of the woman was more injured, having been more frequently exposed; the hair was like that of a living person. Mr. Wormwald, the minister of Hope, was present when they were removed: the man's legs, which had never before been uncovered, were quite fair when the stockings were drawn off, and the joints played freely without the least stiffness.

The Formation of Coal

The time necessary for the accumulation of vegetable matter to make an ordinary bed of coal appears to be extremely long. Huxley (1897, pp. 155-161) in his characteristically entertaining style, discusses this point as follows:

> In the first place, the great phantom of geological time rises before the student of this, as of all other, fragments of the history of our earth—springing irrepressibly out of the facts, like the Djin from the jar which the fishermen so incautiously opened; and like the Djin again, being vaporous, shifting, and indefinable, but unmistakably gigantic. However modest the basis of one's calculation may be, the minimum of time assignable to the coal period remains something stupendous.
>
> Principal Dawson is the last person likely to be guilty of exaggeration in this matter, and it will be well to consider what he has to say about it:—
>
> "The rate of accumulation of coal was very slow. The climate of the period, in the northern temperate zone, was of such a character that the true conifers show rings of growth, not larger, nor much less distinct, than those of many of their modern congeners. The *Sigillariæ* and *Calamites* were not, as often supposed, composed wholly, or even principally, of lax and soft tissues, or necessarily short-lived. The former had, it is true, a very thick inner bark; but their dense woody axis, their thick and nearly imperishable outer bark, and their scanty and rigid foliage, would indicate no very rapid growth or decay. In the case of the *Sigillariæ,* the variations in the leaf-scars in different parts of the trunk, the intercalation of new ridges at the surface representing that of new woody wedges in the axis, the transverse marks left by the stages

of upward growth, all indicate that several years must have been required for the growth of stems of moderate size. The enormous roots of these trees, and the condition of the coal-swamps, must have exempted them from the danger of being overthrown by violence. They probably fell in successive generations from natural decay; and making every allowance for other materials, we may safely assert that every foot of thickness of pure bituminous coal implies the quiet growth and fall of at least fifty generations of *Sigillariæ*, and therefore an undisturbed condition of forest growth enduring through many centuries. Further, there is evidence that an immense amount of loose parenchymatous tissue, and even of wood, perished by decay, and we do not know to what extent even the most durable tissues may have disappeared in this way; so that, in many coal-seams, we may have only a very small part of the vegetable matter produced."

Undoubtedly the force of these reflections is not diminished when the bituminous coal, as in Britain, consists of accumulated spores and spore-cases, rather than of stems. But, suppose we adopt Principal Dawson's assumption, that one foot of coal represents fifty generations of coal plants; and, further, make the moderate supposition that each generation of coal plants took ten years to come to maturity—then, each foot-thickness of coal represents five hundred years. The superimposed beds of coal in one coal-field may amount to a thickness of fifty or sixty feet, and therefore the coal alone, in that field, represents 500 × 50 = 25,000 years. But the actual coal is but an insignificant portion of the total deposit, which, as has been seen, may amount to between two and three miles of vertical thickness. Suppose it be 12,000 feet—which is 240 times the thickness of the actual coal—is there any reason why we should believe it may not have taken 240 times as long to form? I know of none. But, in this case, the time which the coal-field represents would be 25,000 × 240 = 6,000,000 years. As affording a definite chronology, of course such calculations as these are of no value; but they have much use in fixing one's attention upon a possible minimum. A man may be puzzled if he is asked how long Rome took a-building; but he is proverbially safe if he affirms it not to have been built in a day; and our geological calculations are all, at present, pretty much on that footing.

A second consideration which the study of the coal brings prominently before the mind of any one who is familiar with palæontology is, that the coal Flora, viewed in relation to the enormous period of time which it lasted, and to the still vaster period which has elapsed since it flourished, underwent little change while it endured, and in its peculiar characters, differs strangely little from that which at present exist.

The same species of plants are to be met with throughout the whole thickness of a coal-field, and the youngest are not sensibly different from the oldest. But more than this. Notwithstanding that the Carboniferous period is separated from us by more than the whole time represented by the secondary [1] and tertiary formations, the great types of vegetation were as distinct then as now. The structure of the modern club-moss furnishes a complete explanation of the fossil remains of the *Lepidodendra,* and the fronds of some of the ancient ferns are hard to distinguish from existing ones. At the same time, it must be remembered, that there is nowhere in the world, at present, any *forest* which bears more than a rough analogy with a coal-forest. The types may remain, but the details of their form, their relative proportions, their associates, are all altered. And the tree-fern forest of Tasmania, or New Zealand, gives one only a faint and remote image of the vegetation of the ancient world.

Once more, an invariably-recurring lesson of geological history, at whatever point its study is taken up: the lesson of the almost infinite slowness of the modification of living forms. The lines of the pedigrees of living things break off almost before they begin to converge.

---

[1] I.e., the Mesozoic—Ed.

Finally, yet another curious consideration. Let us suppose that one of the stupid, salamander-like Labyrinthodonts, which pottered, with much belly and little leg, like Falstaff in his old age, among the coal-forests, could have had thinking power enough in his small brain to reflect upon the showers of spores which kept on falling through years and centuries, while perhaps not one in ten million fulfilled its apparent purpose, and reproduced the organism which gave it birth: surely he might have been excused for moralizing upon the thoughtless and wanton extravagance which Nature displayed in her operations.

But we have the advantage over our shovel-headed predecessor—or possibly ancestor—and can perceive that a certain vein of thrift runs through this apparent prodigality. Nature is never in a hurry, and seems to have had always before her eyes the adage, "Keep a thing long enough, and you will find a use for it." She has kept her beds of coal many millions of years without being able to find much use for them; she has sent them down beneath the sea, and the sea-beasts could make nothing of them; she has raised them up into dry land, and laid the black veins bare, and still, for ages and ages, there was no living thing on the face of the earth that could see any sort of value in them; and it was only the other day, so to speak, that she turned a new creature out of her workshop, who by degrees acquired sufficient wits to make a fire, and then to discover that the black rock would burn.

I suppose that nineteen hundred years ago, when Julius Cæsar was good enough to deal with Britain as we have dealt with New Zealand, the primæval Briton, blue with cold and woad, may have known that the strange black stone, of which he found lumps here and there in his wanderings, would burn, and so help to warm his body and cook his food. Saxon, Dane, and Norman swarmed into the land. The English people grew into a powerful nation, and Nature still waited for a full return of the capital she had invested in the ancient club-mosses. The eighteenth century arrived, and with it James Watt. The brain of that man was the spore out of which was developed the modern steam-engine, and all the prodigious trees and branches of modern industry which have grown out of this. But coal is as much an essential condition of this growth and development as carbonic acid is for that of a club-moss. Wanting coal, we could not have smelted the iron needed to make our engines, nor have worked our engines when we had got them. But take away the engines, and the great towns of Yorkshire and Lancashire vanish like a dream. Manufactures give place to agriculture and pasture, and not ten men can live where now ten thousand are amply supported.

Thus, all this abundant wealth of money and of vivid life is Nature's interest upon her investment in club-mosses, and the like, so long ago. But what becomes of the coal which is burnt in yielding this interest? Heat comes out of it, light comes out of it; and if we could gather together all that goes up the chimney, and all that remains in the grate of a thoroughly-burnt coal-fire, we should find ourselves in possession of a quantity of carbonic acid, water, ammonia, and mineral matters, exactly equal in weight to the coal. But these are the very matters with which Nature supplied the club-mosses which made the coal. She is paid back principal and interest at the same time; and she straightway invests the carbonic acid, the water, and the ammonia in new forms of life, feeding with them the plants that now live. Thrifty Nature! Surely no prodigal, but most notable of housekeepers!

Swamps in Military Operations

Swamps have played an important rôle in military operations throughout recorded history. A few of the many known battles and campaigns in which swamps figured have been collected by Gregory (1918, p. 106):

During one of the battles of the Seven Years' War (May 6, 1757) a small marshy area near Prague was of disadvantage to the Prussian infantry under Frederick the Great, who, mistaking for meadow land a marshy area in which fish-ponds were coated with green slime, ordered his troops to advance. They struggled through but were shattered by the fire from the Austrian guns.

The severe defeat of Frederick the Great in the battle of Kunnerdorf, near Frankfurt, in 1759, was due more to the natural defenses of the Austrians and Russians than to their military strength. The Austrian left was shielded by impassable swamps, and the right by a dense forest.

Napoleon's campaign in Italy was nearly brought to a disastrous close by the river marshes of the Adige, at Arcola (November, 1796), over which the French could advance only on a causeway and where they were easily held by the Croats. It was here that Napoleon fell into the marsh and was saved from a miry death by his troops.

The combined use of a delta swamp and a river in defensive warfare is illustrated in the battle of New Orleans (January, 1815), where the American Army under General Jackson was entrenched on a front of three-quarters of a mile with its flanks protected on one side by the delta swamp and on the other by the Mississippi River. (This region is shown on the St. Bernard topographic sheet of the United States Geological Survey.)

The Seven Days' Battle, near Richmond, Va., was controlled by the swamps through which the Chickahominy and its tributaries flow and by other swamps. The failure of the Confederate attack at Malvern Hill was in large measure due to swamps which impeded their attacks. Had not McClellan's flanks been protected by White Oaks Swamp and the swamps of the Chickahominy, the Seven Days' Battle would have ended even more disastrously for the Union forces than it did.

During the present war [1914-1918] the marshes along the Save played an important part in the first attempt to invade Serbia, and the delta swamps of the Piave River were partly responsible for the defeat of the Austrians at Capo Sile.

BIBLIOGRAPHY

Chapter VI—Lakes and Swamps

William C. Alden, *Landslide and Flood at Gros Ventre, Wyoming.* American Institute of Mining and Metallurgical Engineers, Technical Publication No. 140, 1928.

Robert Bakewell, *An Introduction to Geology.* 3d American Ed., New Haven, 1839, p. 393.

G. K. Gilbert, Administrative report, 1880, quoted in Memoirs of the National Academy of Sciences, vol. 21, Fifth Memoir, 1927, p. 131.

G. K. Gilbert, *Contributions to the History of Lake Bonneville.* U. S. Geological Survey, 2d Annual Report, 1882, pp. 173-174.

Herbert E. Gregory, *Military Geology and Topography.* New Haven: Yale University Press, 1918, p. 106.

Thomas Huxley, *Discourses Biological and Geological.* New York: Appleton, 1897, pp. 155-161.

John Playfair, *Illustrations of the Huttonian Theory of the Earth.* Edinburgh, 1802, p. 357.

John C. Van Dyke, *The Desert.* New York: Scribner's, 1901, pp. 44-53.

CHAPTER VII

SHORELINES

We stand on a rugged coast and watch the storm waves strike blow after blow, with the relentless persistence of a trip hammer. The display of vast power is impressive, and some disintegration of the rocky walls proceeds before our eyes. Here and there a block between joints is dislodged, and is thrown back by the next wave with shattering force. A layer of weak rock near the base of the cliff yields to undercutting; and if we have chosen a critical moment, when the overhanging ledge is at the point of giving way to gravity, we may witness a cataclysmic fall of the cliff face into the surf, where the broken rock is subject to more effective attack. Our impression from such a scene, taken by itself, is inevitable: the active ocean is at war with the stolid land, and the edge of the continent is retreating before a vigorous onslaught.

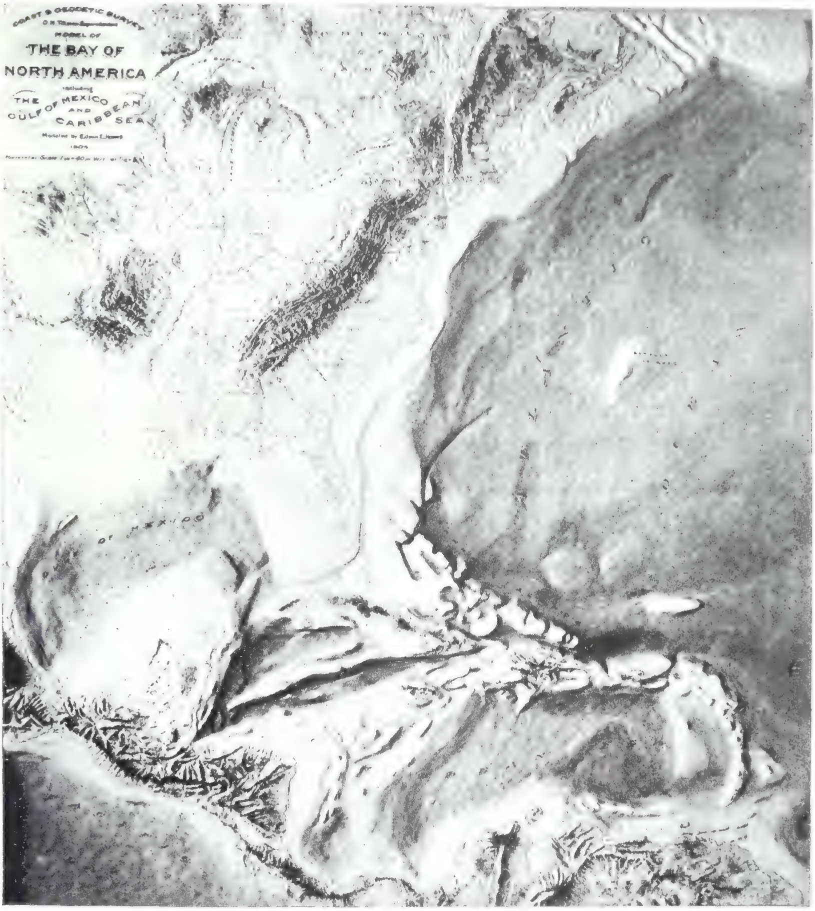
The same impression may result from changes observed on many sandy beaches. If a prolonged "sou'wester" drives against an east-west shore the water, diverted obliquely, rushes along like a mill race; and if the height of the storm comes at high tide, this powerful current cuts rapidly into the upper part of the beach. Inhabitants of cottages on the shore front may awake to find their foundations completely undermined. By a succession of such events some beaches have retreated steadily inland; and along some parts of the drowned Atlantic coast important bars have been cut through entirely, exposing lagoons and marshes to the action of waves and tides.

On the other hand, consider one who may have spent his life on Fire Island, a wide offshore bar east of New York. As a child perhaps he lived in a shore cottage at the west end of the island. To-day the same cottage is three or four miles inland, owing to steady westward growth of the bar through deposition of sand. This limited experience might lead to the conviction that the land is being extended at the expense of the sea. The same thought would occur to observant dwellers near the outer limit of the Niger delta; and for that region, of course, the conclusion would be justified. In short, impressions as to the net effect of wave and current action along shores vary according to one's location.

In many parts of the British Isles the people have seen the ocean advance steadily into the land and so have come to respect the effectiveness of marine erosion. Entire farms that overlooked the cliffs of Dover have disappeared within a few generations; and old roads that once ran continuously parallel to the shore, at a safe distance inland, have been cut by the receding cliffs until only fragments remain, each leading to a precipice that descends to the sea. It is not strange that British geologists make much of wave erosion, and that dwellers along the retreating coasts believe the land will ultimately be destroyed by marine planation. Their point of view is illuminated somewhat by typical extracts from this record (Lyell, 1860, pp. 300-306, 309-311):

> *Destruction of Islands.*—Such devastation cannot be incessantly committed for thousands of years without dividing islands, until they become at last mere clusters of rocks, the last shreds of masses once continuous. To this state many appear to have been reduced, and innumerable fantastic forms are assumed by rocks adjoining these islands to which the name of Drongs is applied, as it is to those of similar shape in Feroe.
>
> The granite rocks between Papa Stour and Hillswick Ness afford an example. A still more singular cluster of rocks is seen to the south of Hillswick Ness, which presents a variety of forms as viewed from different points, and has often been likened to a small fleet of vessels with spread sails. We may imagine that in the course of time Hillswick Ness itself may present a similar wreck, from the unequal decomposition of the rocks whereof it is composed, consisting of gneiss and mica-schist traversed in all directions by veins of felspar-porphyry.
>
> Midway between the groups of Shetland and Orkney is Fair Island, said to be composed of sandstone with high perpendicular cliffs. The current runs with such velocity, that during a calm, and when there is no swell, the rocks on its shores are white with the foam of the sea driven against them.

PLATE XVII



U. S. Coast and Geodetic Survey

THE OCEAN FLOOR

Relief model showing relation of the western Atlantic basin to eastern North America. Note the relative depths, indicated by shading. The model represents what would be seen if all the ocean water were removed.

The Orkneys, if carefully examined, would probably illustrate our present topic as much as the Shetland group. The north-east promontory of Sanda, one of these islands, has been cut off in modern times by the sea, so that it became what is now called Start Island, where a lighthouse was erected in 1807, since which time the new strait has grown broader.

East Coast of Scotland.—To pass over to the mainland of Scotland, we find that in Inverness-shore there have been inroads of the sea at Fort George, and others in Morayshire, which have swept away the old town of Findhorn. On the coast of Kincardineshire, an illustration was afforded at the close of the last century, of the effect of promontories in protecting a line of low shore. The village of Mathers, two miles south of Johnshaven, was built on an ancient shingle beach, protected by a projecting ledge of limestone rock. This was quarried for lime to such an extent that the sea broke through, and in 1795 carried away the whole village in one night, and penetrated 150 yards inland, where it has maintained its ground ever since, the new village having been built farther inland on the new shore. In the bay of Montrose, we find the North Esk and the South Esk rivers pouring annually into the sea large quantities of sand and pebbles; yet they have formed no deltas, for the waves, aided by the current, setting across their mouths, sweep away all the materials. Considerable beds of shingle, brought down by the North Esk, are seen along the beach.

Proceeding southwards, we learn that at Arbroath, in Forfarshire, which stands on a rock of red sandstone, gardens and houses have been carried away since the commencement of the present century by encroachments of the sea. It had become necessary before 1828, to remove the lighthouses at the mouth of the estuary of the Tay, in the same county, at Button Ness, which were built on a tract of blown sand, the sea having encroached for three-quarters of a mile. . . .

. . . *Coast of Yorkshire.*—Almost the whole coast of Yorkshire, from the mouth of the Tees to that of the Humber, is in a state of gradual dilapidation. That part of the cliffs which consist of Lias [Jurassic], the oölite series, and chalk, decays slowly. They present abrupt and naked precipices, often 300 feet in height; and it is only at a few points that the grassy covering of the sloping talus marks a temporary relaxation of the erosive action of the sea. The chalk cliffs are worn into caves and needles in the projecting headland of Flamborough, where they are decomposed by the salt spray, and slowly crumble away. But the waste is most rapid between that promontory and Spurn Point, or the coast of Holderness, as it is called, a tract consisting of beds of clay, gravel, sand, and chalk rubble. The irregular intermixture of the argillaceous beds causes many springs to be thrown out, and this facilitates the undermining process, the waves beating against them, and a strong current setting chiefly from the north. The wasteful action is very conspicuous at Dimlington Height, the loftiest point in Holderness, where the beacon stands on a cliff 146 feet above high water, the whole being composed of clay, with pebbles scattered through it. "For many years," says Professor Phillips, "the rate at which the cliffs recede from Bridlington to Spurn, a distance of thirty-six miles, has been found by measurement to equal on an average two and a quarter yards annually, which, upon thirty-six miles of coast, would amount to about thirty acres a year. At this rate, the coast, the mean height of which above the sea is about forty feet, has lost one mile in breadth since the Norman Conquest, and more than two miles since the occupation of York (Eboracum) by the Romans."

In the old maps of Yorkshire, we find spots, now sandbanks in the sea, marked as the ancient sites of the towns and villages of Auburn, Hartburn, and Hyde. "Of Hyde," says Pennant, "only the tradition is left; and near the village of Hornsea, a street called Hornsea Beck has long since been swallowed." Owthorne and its church have also been in great part destroyed, and the village of Kilnsea; but these places are now removed farther inland. The annual rate of encroachment at Owthorne for several years preceding 1830, is stated to have averaged about four yards. Not unreasonable fears are entertained that at some future time the Spurn Point will become an island, and that the ocean, entering in to the estuary of the Humber, will cause great devastation. Pennant, after speaking of the silting up of some ancient ports in that estuary, observes, "But, in return, the sea has made most ample reprisals; the site, and even the very names of several places, once towns of note upon the Humber, are now only recorded in History. Ravensper was at one time a rival to Hull, and a port so very considerable in 1332, that Edward Baliol and the confederated English barons sailed from hence to invade Scotland; and Henry IV, in 1399, made choice of this port to land at, to effect the deposal of Richard II; yet the whole of this has long since been devoured by the merciless ocean; extensive sands, dry at low water, are to be seen in their stead."

Pennant describes Spurn Head as a promontory in the form of a sickle, and says the land, for some miles to the north, was "perpetually preyed on by the fury of the German Sea, which devours whole acres at a time, and exposes on the shores considerable quantities of beautiful amber."

Lincolnshire.—The maritime district of Lincolnshire consists chiefly of lands that lie below the level of the sea, being protected by embankments. Some of the fens were embanked and drained by the Romans; but after their departure the sea returned, and large tracts were covered with beds of silt, containing marine shells, now again converted into productive lands. Many dreadful catastrophes are recorded by incursions of the sea, whereby several parishes have been at different times overwhelmed.

Norfolk.—The decay of the cliffs at Norfolk and Suffolk is incessant. At Hunstanton, on the north, the undermining of the lower arenaceous beds at the foot of the cliff, causes masses of red and white chalk to be precipitated from above. Between Hunstanton and Weybourne, low hills, or dunes, of blown sand, are formed along the shore, from fifty to sixty feet high. They are composed of dry sand, bound in a compact mass by the long creeping roots of the plant called Marram. Such is the present set of the tides, that the harbors of Clay, Wells, and other places are securely defended by these barriers; affording a clear proof that it is not the strength of the material at particular points that determines whether the sea shall be progressive or stationary, but the general contour of the coast.

The waves constantly undermine the low chalk cliffs, covered with sand and clay, between Weybourne and Sherringham, a certain portion of them being annually removed. At the latter town I ascertained, in 1829, some facts which throw light on the rate at which the sea gains upon the land. It was computed, when the present inn was built, in 1805, that it would require seventy years for the sea to reach the spot; the mean loss of land being calculated, from previous observations, to be somewhat less than one yard, annually. The distance between the house and the sea was fifty yards; but no allowance was made for the slope of the ground being *from* the sea, in consequence of which the waste was naturally accelerated every year, as the cliff grew lower, there being at each succeeding period less matter to remove when portions of equal area fell down. Between the years 1824 and 1829, no less than seventeen yards were swept away, and only a small garden was then left between the building and the sea. There was in 1829, a depth of twenty feet (sufficient to float a frigate) at one point in the harbor of that port, where, only forty-eight years before, there stood a cliff fifty feet high, with houses upon it! If once in half a century an equal amount of change were produced suddenly by the momentary shock of an earthquake, history would be filled with records of such wonderful revolutions of the earth's surface; but, if the conversion of high land into deep sea be gradual, it excites only local attention. The flagstaff of the Preventive Service station, on the south side of this harbor, was twice removed inland between the years 1814 and 1829, in consequence of the advance of the sea.

Farther to the south we find cliffs, composed, like those of

Holderness before mentioned, of alternating strata of blue clay, gravel, loam, and fine sand. Although they sometimes exceed 300 feet in height, the havoc made on the coast is most formidable. The whole site of ancient Cromer now forms part of the German Ocean, the inhabitants having gradually retreated inland to their present situation, from whence the sea still threatens to dislodge them. In the winter of 1825, a fallen mass was precipitated from near the lighthouse, which covered twelve acres, extending far into the sea, the cliffs being 250 feet in height. The undermining by springs has sometimes caused large portions of the upper part of the cliffs, with houses still standing upon them, to give way, so that it is impossible, by erecting breakwaters at the base of the cliffs, permanently to ward off the danger.

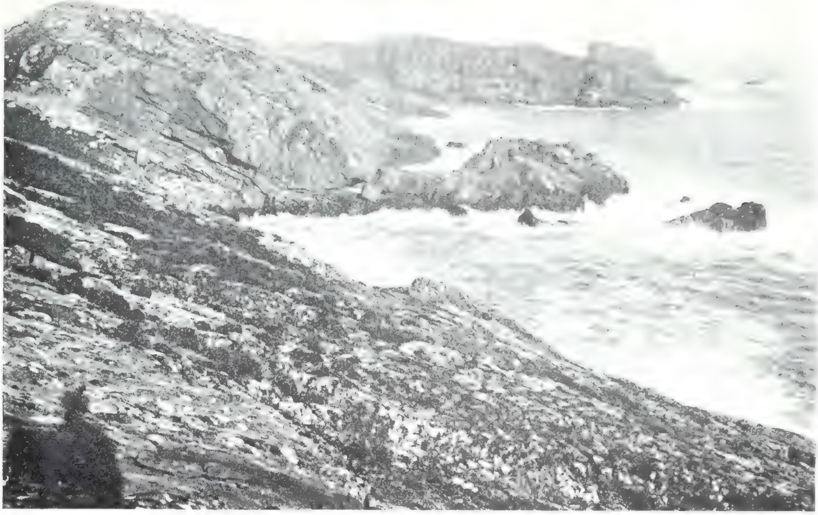
On the same coast, says Mr. R. C. Taylor, the ancient villages of Shipden, Wimpwell, and Eccles have disappeared; several manors and large portions of neighboring parishes having, piece after piece, been swallowed up; nor has there been any intermission, from time immemorial, in the ravages of the sea along a line of coast twenty miles in length, in which these places stood. Of Eccles, however, a monument still remains in the ruined tower of the old church, which is half buried in the dunes of sand within a few paces of the sea-beach. So early as 1605 the inhabitants petitioned James I for a reduction of taxes as 300 acres of land, and all their houses, save fourteen, had been destroyed by the sea. Not one-half that number of acres now remains in the parish, and hills of blown sand now occupy the site of the houses which were still extant in 1605. When I visited the spot in 1839, the sea was fast encroaching on the sand-hills, and had laid open on the beach the foundations of a house fourteen yards square, the upper part of which had evidently been pulled down before it had been buried under sand. The body of the church has also been long buried, but the tower still remains visible. . . .

. . . *Destruction of Dunwich by the Sea.*—Of the gradual destruction of Dunwich, once the most considerable seaport on this coast, we have many authentic records. Gardner, in his history of that borough, published in 1754, shows, by reference to documents, beginning with Doomsday Book, that the cliffs at Dunwich, Southwold, Eastern, and Pakefield, have been always subject to wear away. At Dunwich, in particular, two tracts of land which had been taxed in the eleventh century, in the time of King Edward the Confessor, are mentioned in the Conqueror's survey, made but a few years afterwards, as having been devoured by the sea. The losses, at a subsequent period, of a monastery,—at another of several churches,—afterwards of the old port,—then of four hundred houses at once,—of the church of St. Leonard, the high-road, town-hall, jail, and many other buildings, are mentioned, with the dates when they perished. It is stated that, in the sixteenth century, not one-quarter of the town was left standing; yet the inhabitants retreating inland, the name was preserved, as has been the case with many other ports when their ancient site has been blotted out. There is, however, a church of considerable antiquity still standing, the last of twelve mentioned in some records. In 1740, the laying open of the churchyard of St. Nicholas and St. Francis, in the sea-cliffs, is well described by Gardner, with the coffins and skeletons exposed to view—some lying on the beach, and rocked

> "In cradle of the rude imperious surge."

Of these cemeteries no remains can now be seen. Ray also says, "that ancient writings make mention of a wood a mile and a half to the east of Dunwich, the site of which must at present be so far within the sea." This city, once so flourishing and populous, is now a small village, with about twenty houses, and one hundred inhabitants.

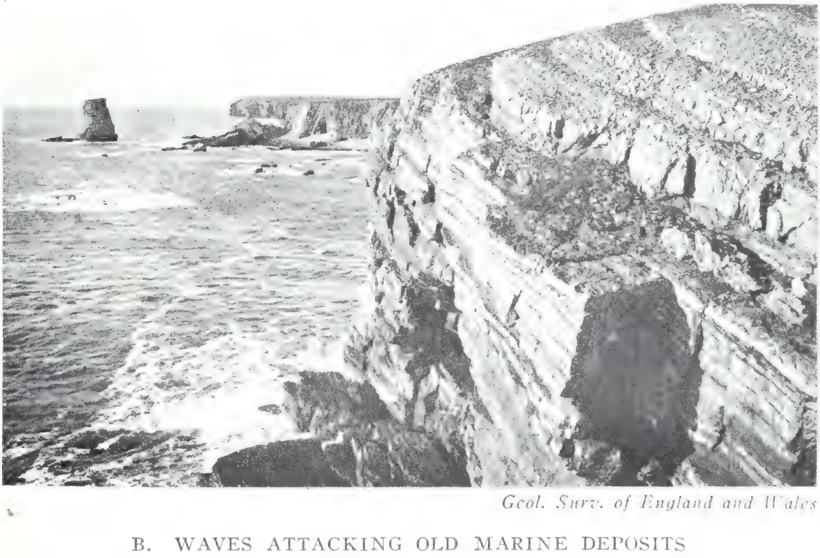
There is an old tradition "that the tailors sat in their shops at Dunwich, and saw the ships in Yarmouth Bay"; but when we consider how far the coast at Lowestoff Ness projects between these places, we cannot give credit to the tale, which, nevertheless, proves how much the inroads of the sea in times



Geol. Surv. of England and Wales

A. A ROCKY COAST

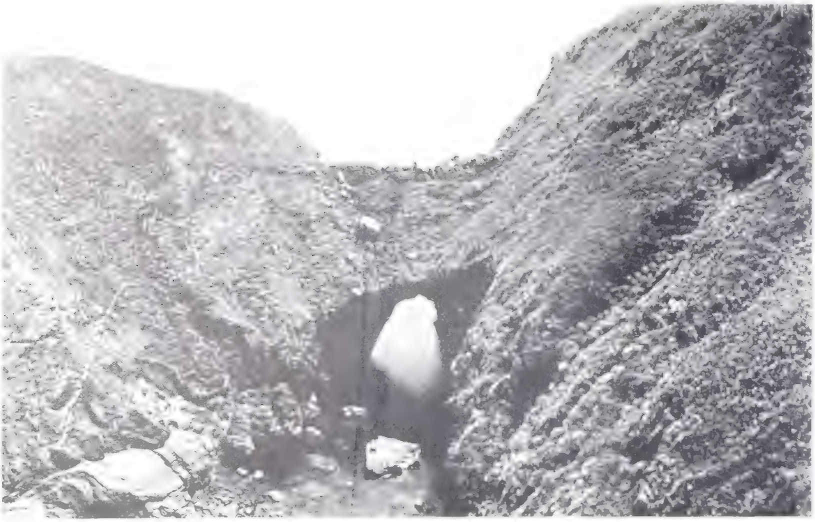
Cliffs of rhyolite and basalt lava, Skomer Island, Pembroke, Wales.



Geol. Surv. of England and Wales

B. WAVES ATTACKING OLD MARINE DEPOSITS

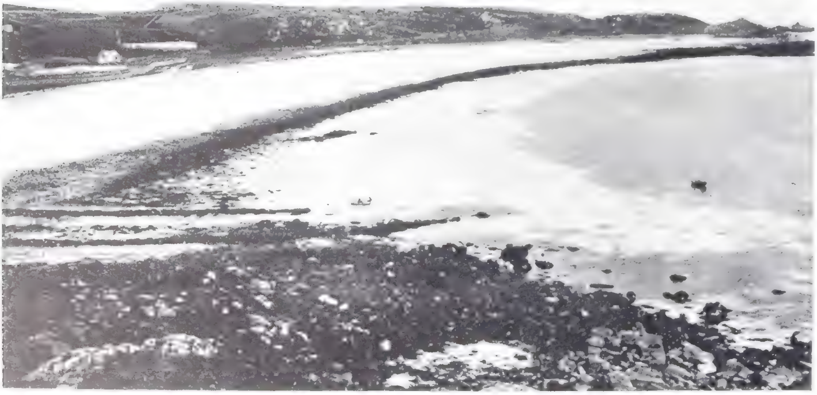
Note the stratified rocks, laid down in an old seaway, uplifted, and now undergoing destruction by the sea. A stack stands in the left background.



Geol. Surv. of England and Wales

A. DEVIL'S FRYING PAN

An arch eroded by the sea. Cadgwith, Cornwall.



Geol. Surv. of England and Wales

B. BEACH AND SAND HILLS

The hills are made of wind-blown sand derived from the beach. St. Martins, Scilly, Cornwall.

of old had prompted men of lively imagination to indulge their taste for the marvelous.

Gardner's description of the cemeteries laid open by the waves reminds us of the scene which has been so well depicted by Bewick, and of which numerous points on the same coast might have suggested the idea. On the verge of a cliff, which the sea has undermined, are represented the unshaken tower and western end of an abbey. The eastern isle is gone, and the pillars of the cloister are soon to follow. The waves have almost isolated the promontory, and invaded the cemetery, where they have made sport with the mortal relics, and thrown up a skull upon the beach. In the foreground is seen a broken tombstone, erected, as its legend tells, "to *perpetuate* the memory"—of one whose name is obliterated, as is that of the county for which he was "Custos Rotulorum." A cormorant is perched on the monument, defiling it, as if to remind some moralizer like Hamlet, of "the base uses" to which things sacred may be turned. Had this excellent artist desired to satirize certain popular theories of geology, he might have inscribed the stone to the memory of some philosopher who taught "the permanency of existing continents"—"the era of repose"—"the impotence of modern causes."

The incursions of the sea at Aldborough were formerly very destructive, and this borough is known to have been once situated a quarter of a mile east of the present shore. The inhabitants continued to build farther inland, till they arrived at the extremity of their property, and then the town decayed greatly; but two sand-banks, thrown up at a short distance, now afford a temporary safeguard to the coast. Between these banks and the present shore, where the current now flows, the sea is twenty-four feet deep on the spot where the town formerly stood.

Sandy Hook and Barnegat are familiar landmarks on the New Jersey coast. The first is a spit which grows steadily northward toward New York Harbor, through transfer and deposit of sand by the shore current; Barnegat is an inlet which maintains its width but shifts its position bodily by erosion of the bar on the south side and compensating growth of the bar on the north. The "Jersey" coast is notably sandy. In places it is being cut away, but locally it has grown seaward at a conspicuous rate.

The general character of the changes is stated by a geologist (Haupt, 1905, pp. 36, 37) familiar with the coast through long study:

> The Geological Survey has, at different times, collected such information as was available from reliable sources, by personal itineraries along the coast, and has embodied it in the reports of the State Geologist, notably in the year 1885, when the testimony of the keepers of the Life Saving Service and others was published as to the changes which had been taking place, based upon their personal observations for many years. From these data the general conclusion was reached that there is an extensive wear along the east side of the beaches of the New Jersey coast effecting a change in their position, which in many cases has amounted to a lateral movement exceeding the width of the beach. This movement is still going on with undiminished activity, and although there have been local accretions they are so limited in extent that "it is accepted as a rule that on the east shore the loss is absolute while the gain is but relative." . . .
>
> . . . Not only are the beaches being driven back by the sea, but the harbors which were accessible to coasters, within the memory of men now living near them, are being closed by the traveling drift. A glance at the maps of the Survey will show that most of the mouths of streams emptying into the ocean have been closed and the salt water estuaries are now converted into marshes or fresh water lakes. It is also suggestive as to the direction of movement of the obstructing sand to observe that from Sandy Hook to Bay Head the longer axis of these lakes is inclined to the northward at their outer ends, whilst below the latter point the beach is separated from the main land by broad bays and marshes having a sandy cordon with numerous inlets which are in general drifting to the south. A

most remarkable topographic feature of the coast is the 70-mile terrace extending in a straight line from Barnegat to Cape May, and forming the western escarpment to the salt marshes which cover some 300,000 acres of land reaching from 2 to 6 miles seaward.

Keepers of lighthouses and of the Life Saving Service see the shifting of shore features year by year. Their testimony is valuable, especially if it is based on repeated measurements with relation to fixed points. Examples of summary reports from Life Saving Stations follow (Haupt, 1905, p. 41):

Sta. No. 3. The shore has washed away about 200 feet in 20 years, and at Seabright it is rapidly encroached upon.

Sta. No. 12. In the past 35 years the shore has grown out 200 feet. The drifting sands have covered up the meadow for a considerable distance east of the railroad.

Sta. No. 16. The beach is constantly making to the west, due to the wear of the shore at the rate of about 50 feet in 40 years. Near the south end the beach is flat and of recent formation. It appears to be working westward.

Barnegat Inlet is working south without material change of width. The old light house (built 1834) has been destroyed.

Sta. No. 25. The wear of the north point was from 75 to 175 yards per year for the past five years, while that of the east shore was from 4 to 16 yards per year. The inlet wears most on south side.

Sta. No. 27. The point at the south side of Absecon Inlet has worn away 400 yards in 20 years, and along the east shore the wear has been nearly a half mile in 30 years. The building of jetties since about 1878 has stopped the wear and recovered much of the lost beach at the point.

Sta. No. 35. The dunes are 40 feet high, and are moving westward and engulfing the trees. The rate of this movement is 20 yards in 12 years. The old thoroughfare on the inside has been closed by sand washed over the beach half a mile southwest of the station.

The Legal Aspect of the Problem

Survey marks are of little value unless they are permanent. In the country removed from the coast, land corners are established by stone or metal posts, and these can be trusted to keep their positions. But what if the land itself is mobile, so that it migrates from one locality to another? Can anyone recognize the particles of soil, and claim them as his own after they have been swept away from a set of landmarks and deposited a mile or two distant? The legal difficulties that result from constant remolding of coastal features are numerous and vexatious. A few examples are given (Haupt, 1905, pp. 46-48):

> Many of the ancient grants and charters to territory along the seaboard were based upon the existing landmarks as determined by the position of inlets or other natural water courses. As has been seen these are subject to constant changes due to the ever varying forces operating on mobile materials, so that in the absence of permanent monuments or fixed channels much confusion has arisen, causing expensive litigation.
>
> Thus the beginning corner of "Keith's Line" separating East from West New Jersey was at the northerly point of Little Egg Harbor Inlet, as shown on the map of Sellers and Fisher (1676), as well as on the survey made by Ratzer, in 1769. On this chart the point of the beach is placed in latitude 39° 32′, which is the present position of Life-Saving Station No. 22, as shown on the Geological Survey Chart of 1885, on which the beginning corner is located on the beach one-quarter of a mile to the south of the station, while the point of the island is 3.9 miles below. On the United States Coast and Geodetic Chart of September, 1904, the distance from the Life-Saving Station to the point of the inlet is 4.64 miles. From these data it appears that the progression of this spit to the southward has been at the average rate of 168 feet per annum in the period from 1769 to 1885 and about 200 feet per annum subsequently.
>
> A title based upon so great mobility of its initial landmark would have little validity. This was illustrated in the case of the boundary line between Atlantic and Burlington counties,

which was in litigation about 1885 when much valuable testimony was taken as to the uncertainty of the position of the inlets and beaches. The "corner" in question was defined to be, "The next inlet in the south side of Little Egg Harbor's most southerly inlet and thence along the sea coast to the line of partition between East and West Jersey." Had this last course contained even an approximate distance the nameless inlet might have been identified and the numerous disputes over property, oyster and fishing rights, have been avoided. This deed was dated as far back as 1709, or beyond the memory of any living person.

Again in a suit for title to the beach front at Hempstead, Long Island, the Supreme Court has recently ruled, "That old maps of the beach on Long Island are but slight evidence of the condition of the beach or the location of the inlets at a period fifty years earlier, even though correct at the time made. It is a fair presumption that the constant shifting in the various inlets of Rockaway Beach on Long Island, shown to be going on at the present time, was going on in 1725." From this it would appear that such a description as is contained in the deed of "A beach lying on the south side of the Island at a place called Rockaway" is not one that would convey title to a definite tract of land subject to the action of such physical forces as prevail on alluvial coasts.

Changing of Inlets

The slow shifting of a sandy bar by the ordinary process of cut and fill is not difficult to comprehend; but migration of an inlet without appreciable change in its width requires a more complicated mechanism. These inlets are simply gaps across bars, and many of them are located near the mouths of streams. The shore current tends to fill each gap by extending the bar on one side; but the filling is prevented by scour of the tides moving in and out. The strength of the current is sufficient to maintain some growth of the bar, but by way of compensation the tides keep cutting back the bar on the other side of the inlet. Therefore the entire inlet changes its position slowly. But a perfect balance between currents and tides is not maintained, and some of the inlets that are important in navigation become shallow or even nearly closed by the action of unusual storms. Difficulties that arise along the New Jersey coast are typical (Haupt, 1905, pp. 49-50):

> The changes of greater importance, from the standpoint of commerce, are those which are taking place at the inlets. Even the most casual examination shows that these are constantly shifting their positions, changing in depth and in some cases filling up completely. From time to time efforts have been made to control these changes in some instances, but little has been accomplished, although that little is of value as a guide for future efforts at improvement.
>
> As each inlet is a special problem a brief description of the most important will be given . . .
>
> *Shark River.*—Shark River is the only stream of any importance between the Shrewsbury River to the north and Manasquan River at the south. It spreads out over a broad extent of flat land, forming a shallow bay connected with the ocean by a narrow passage the mouth of which is constantly shifting and is sometimes closed for weeks together. The following account taken from the "State Gazette," of August, 1877, describes the conditions prevailing at that time:
>
> > Shark River, at Ocean Beach (now Belmar), has been closed to the sea all the summer by the northeasterly storms of the spring. It has been steadily filling up all the season, until the fresh water began to have a bad effect upon the beds of famous Shark River oysters, and the clams, crabs, etc., with which it abounds. The fishermen and oystermen have been anxious to get it open and have the tides pour in the accustomed volume of salt sea-water. Several efforts have lately been made to that end, but without success, until Saturday evening last, when an opening was made through the wide ridge of sand that separated the accumulated water of the river from the sea, and at low tide it began to tear away the sand. In the course of a short time it had torn away and carried into the ocean thousands of tons of sand and formed a deep and rapid current, which swept through the ever-widening gap with terrific force. It created a turbulent and swift current far out into the ocean, and was

a really magnificent spectacle. Shark River widens out into a large bay fully two miles wide a short distance back from the ocean, and as this had risen fully three feet, the vast quantity of water that had to escape may readily be imagined. It took from Saturday night to Monday forenoon for the river to fall to its normal level.

This account, written within a few days of the opening, did not give the sequel, which was that the littoral drift rolling northwardly speedily closed the mouth of the cut as before and since. The closure of this large salt-water bay converts it into a stagnant fresh-water basin and kills the marine life, so that it becomes necessary for the health of the neighborhood to admit the salt water by reopening the channel across the spit of sand which separates the bay from the sea. Various efforts have been made by means of sand catches, fences and piling to compel the currents to maintain a fixed channel, but with only temporary benefit.

Tides, shore currents, and storm waves are the principal agents in modifying inlets; but the sum total of changes along a coast involves a complex interplay of many factors. Some of these are suggested by Haupt (1905, pp. 78-79):

To ascribe the physical changes on alluvial coasts to the preponderating influences of one or more of the forces, as is frequently done, would manifestly lead to erroneous conclusions and failures in the proposed remedies. Evidently, all the elements must receive their due weight, and since no extended instrumental observations can give so reliable an indication as those recorded upon the plastic material of the sandy beaches themselves, it will afford a better clue to the operation of the forces to note carefully their effects by a thorough study of the positions of the shoals, and channels, with their cross sections and slopes, as indicative of the directions of their movements.

The elements which must be considered are therefore the tides, currents, winds, waves, nature of the material composing the strand, position of the water contours, slopes of the foreshore, angle of wave impingement, frequency and size of breaches in the coast, capacity and form of interior tidal compartments, amount of land drainage, rate and amount of littoral drift, and local accidents interrupting the continuity of the movements, whether natural, as in rocky headlands, or accidental as from wrecks; in short, not only the local and terrestrial, but the cosmic influences must be considered as factors in producing the observed effects.

Changes of Level

The quotation above indicates the complexity of shore processes, and yet the conditions assumed in the statement are relatively simple. Nothing is said about the effects of uplift and subsidence in modifying shorelines; but vertical movements of the land are so common, and their influence on shore features is so pronounced, that any discussion of shore development necessarily distinguishes between shorelines of *emergence* and those of *submergence*. Most of the Atlantic coast of the United States, with its deeply embayed valleys and extensive salt-water marshes, is a typical *drowned* or *submerged* coast. From the vicinity of Boston northward, however, recent emergence is recorded in elevated wave-cut terraces, and other features that were developed at or just below sea level. Along the coast of Maine marine clays are found on the slopes to an altitude of about 100 feet. This recent uplift has not been sufficient, however, to overcome the effects of an earlier sinking which is responsible for the numerous islands, promontories, and long estuaries that add to the attractiveness of the Maine coast.

Evidences of extensive emergence in recent and more remote times are recorded along some of the coasts of all continents. Elevated strand lines are especially conspicuous in California, where successive wave-cut benches, raised by a series of uplifts with long intervening pauses, resemble a set of gigantic steps that lead from present sea level to a height exceeding 1,500 feet. The west coast of South America has similar terraces at even higher altitudes. These old strand lines retain many typical shore features, such as caves, arches, and stacks, as well as typical beach ridges. Shells and other relics of marine life are found on some of the old beaches and platforms. Naturally the lowest terraces are most distinct, since they have been exposed only a short time. Those at high elevations have been dissected and dimmed by erosion.

Italy, still a region of crustal unrest as indicated by frequent severe earthquakes, is famous for its high marine terraces. Other Mediterranean coasts have similar indications of uplift. Two excellent remnants of former sea floors appear in profile on the west side of Gibraltar as seen from a steamship entering the strait. One of these platforms is 120 feet, the other 370 feet above sea level (Pl. XX, A).

As the land rises the streams cut with renewed energy, and therefore the valleys along a recently emerged coast are eroded to or near the present sea level. There are no tidal estuaries in these valleys, however, such as characterize submerged coasts. Shorelines of emergence are typically smooth in contrast to the tortuous outline that results from subsidence.

Visitors to the coasts of Norway, Iceland, Patagonia, and other lands in high latitudes are impressed by the deep fiords that extend to great distances inland. Naturally the thought comes that these canyon-like waterways, into which tidewater extends tens of miles from the general shoreline, indicate subsidence of the land. It is true that the drowning of steep-walled stream valleys would produce typical fiords; but most of the fiorded valleys that have been studied have had a peculiar history. Glaciation has had a prominent part in deepening and otherwise fashioning them, and since glacial erosion is not controlled by sea level it is possible that subsidence of the land has not been necessary in admitting the sea water after the glaciers disappeared. In fact some of the finest and deepest fiords are on coasts that have been uplifted instead of lowered since the Ice Age, according to the clear testimony of raised beaches. There has been some drowning of the overdeepened valleys, however, owing to a considerable rise of the general sea level. While the continental glaciers were in their prime a vast quantity of ocean water was held on the lands in the form of ice. With the melting of the ice caps this water was liberated, and sea level rose two or three hundred feet above the position it held while the present fiorded valleys were being scoured by glacial action.

The importance of fiords in human affairs is explained by J. W. Gregory (1913, pp. 1-3):

Fiords have become a powerful factor in modern life, for from them came the facility of intercourse by sea which marks the most influential difference between modern and mediæval Europe. The Roman Empire was held together by its roads; *terra marique* was the phrase familiar to Roman ears, instead of "by sea and land"; and, as its conquerors from the wide plains of the East were neither sailors nor roadmakers, Europe was resettled on national, instead of on imperial, lines. While Europe thus fell naturally into independent States, the beginnings of modern seamanship were being developed in Scandinavia; for travel overland in that country, owing to its fiords, was even more difficult than through the forest-clad plains of north-central Europe. The fiords in Norway were the only practicable highways; with their labyrinth of smooth-water channels, with their tidal currents which carried boats to and fro independent of wind and oar, with their unfailing supplies of fish and oil, of whale-hide and seal-skins, the fiords attracted men to the sea, as much as the barren highlands repelled them from the land.

The poverty of their own country drove the Norsemen to the sea; the wealth of the more fertile southern coast-lands tempted them to that career of piracy which for centuries made the northern berserkers the terror of the shores of western and southern Europe. These pirates, however, amply repaid their debt to the world at large by their contributions to modern seamanship. It was probably their influence which led to the development of the Saxon shepherds into the British Sea-kings, and to the revival of the ancient sea-craft of north-western France. It was doubtless the descendants of the Norse settlers in Sicily who helped to beat back the Turkish corsairs and Barbary pirates, and thus saved the western Mediterranean from falling under the Mahometan power.

Modern seamanship, with its incalculable contribution to the wealth and comfort of mankind, was first developed in consequence of the peculiar geographical conditions of the Norwegian fiords. . . .

The white sails of the Norse and Danish Vikings carried the name "fiord" far and wide. It is found on the Irish coast, in Wexford, which is said to be derived from the Danish Weisfiord, and in Waterford which comes from Vadre-Fiord; and the name "fiord" is now accepted as a technical term in general geographical nomenclature.

In Norway the word "fiord" is used for any arm of the sea, including various types of gulfs, bays, and straits. But in international geography the name is adopted for arms of the sea of a special character. A fiord, in this restricted sense, is a long inlet which extends far inland between steep, opposing walls; it usually consists of long, straight reaches, which turn and receive their tributaries at sharp and regular angles; and its walls are high, as fiords are restricted to mountain regions.

Fiord districts combine the features of mountain and coastal scenery. Many authors have been impressed by a sense of monotony of fiord scenery, owing to the constant repetition of the same form; it is, however, popular from its ease of access along the smooth waterways, the especial beauty of its cloud-forms and exquisite colour effects, which do not pass with the flash of a tropical sunset, but last for hours in the prolonged twilight of most fiord areas. The charm of fiord countries is, moreover, enhanced by the survival of primitive conditions of life owing to their comparative isolation and cramped areas of cultivation.

The principal natural causes concerned in changing patterns of shores have been considered above. But more and more in modern times man has turned his engineering skill to combating or controlling the forces that build and destroy coastal features; and since man is a part of Nature his influence cannot be excluded from the list of natural factors. He erects jetties to prevent silting at the mouths of rivers; he builds sea walls and breakwaters to prevent erosion or to induce sedimentation in critical localities; and he even wrests large areas from the domain of the sea by building and maintaining elaborate systems of dikes. His efforts in fashioning the coasts to suit his will appear puny when compared in the large with the effects of waves and currents or with the hidden forces that raise and lower coastal lands. In the future, however, the influence of human genius in controlling the development of shorelines is sure to increase. The nature of the problems and the need for their solution are explained by D. W. Johnson (1927, pp. 135-136):

> Every winter the public press records ravages effected by storm waves on one or more parts of our exposed coast. Now it is New Jersey which is the victim, with board walks and boulevards undermined and costly summer residences and big hotels destroyed. Again Florida is the sufferer, and columns of print are required to chronicle the devastation wrought by wind and sea along the margins of the land of fruit and flowers. The Galveston disaster is still fresh in memory. At one time or another the ocean takes toll of every coastal state from Maine to Texas and from southern California to the northern shores of Washington.
>
> The problem of coast protection is becoming more acute every year. The automobile is bringing the population of the interior to the seashore in ever-increasing crowds, property values along the sea are mounting rapidly, and demands for good bathing beaches are forcing municipalities to expend millions to preserve present beaches from destruction or to create new beaches where naturally only mud flats or jagged rocks were found. Unfortunately efforts at beach formation and coast protection have too frequently proved of little effect.
>
> Only through cooperative studies extending over a long stretch of sea front can there be collected a large body of carefully observed facts from which may be disengaged the general principles controlling coast erosion. Shore processes are peculiarly complex. Wave action varies with the strength of the wind, with the direction from which it blows, with the extent of open water over which it passes, with the depth of the water, with the form of the sea bottom, with the shape of the shore line, with the direction of tidal or other currents, with the height of the tide, and with other factors. Current action

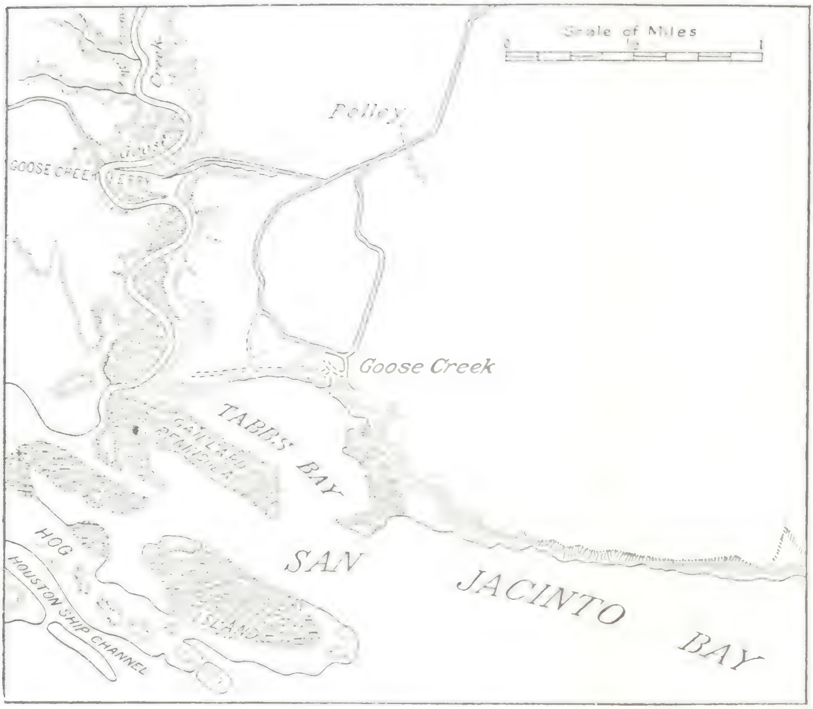
is similarly variable. At no two places on the coast do natural forces operate in precisely the same manner; and seldom, if ever, do they behave twice in precisely the same manner at any given point.

Cooperation in the work of designing and constructing coast defenses is equally necessary. The writer has elsewhere described the damage wrought on well protected property where the waves "outflanked" the defenses by first attacking unprotected areas on either side. On the shore every man is his neighbor's keeper. Even the man back of the shore is vitally concerned in the matter of coast protection, for he must pay, in the form of increased taxes, for every foot of land conquered by the sea. The city, the country, and the state are interested parties, since they all suffer when land and buildings are destroyed, just as they gain when shore resorts become great contributors to their wealth.

Some of man's activities near the shore have a wholly unexpected effect. A recent development along the coast of Texas appears to be entirely unique (Pratt and Johnson, 1926, pp. 577-582):

> The low flat coastal plain of Texas, following a geologically recent uplift of the coast, was bordered on its seaward side by a more or less continuous offshore bar separating a shallow lagoon from the open waters of the Gulf of Mexico. The fairly typical "shoreline of emergence" thus produced was later modified by a slight submergence which partly drowned the lower ends of valleys draining into the Gulf, so that to-day the inner margin of the lagoon frequently makes broad indentations into the land. Galveston Bay is such an indentation, and one of its subdivisions on the northwest is known as San Jacinto Bay. Into the latter body of water drains a little stream known as Goose Creek (Fig. 4).
>
> In 1917 a prolific oil field was developed near the mouth of Goose Creek, and during 1918 and subsequent years, millions of barrels of oil were removed from beneath its surface. Be-

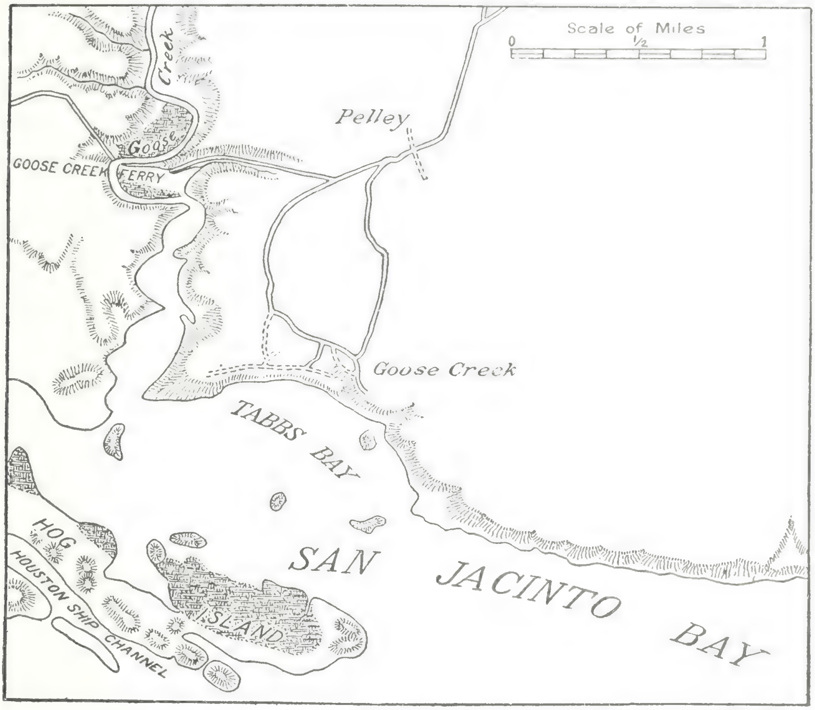
ginning in 1918 it became apparent that Gaillard Peninsula, near the center of the field and other nearby low land was becoming submerged (Fig. 5). Elevated plank roadways or walks were built from the mainland to the derricks. Derrick floors had to be raised. Vegetation was flooded and killed, and finally all of the peninsula disappeared beneath the water. The change appeared to be gradual but did not go unnoticed. The maximum measured subsidence is now more than 3 feet and the area affected is 2½ miles long by 1½ miles wide, the longer axis running approximately east-west. Outside this area no change in elevation can be detected, although repeated careful levels have been taken at intervals, both within the submerged area and outside of it.



—*Journal of Geology*

FIG. 4.—GOOSE CREEK REGION BEFORE SUBSIDENCE.

In the little town of Pelley on the northern edge of the oil field, cracks appeared in the ground running beneath houses, across streets, and through lawns and gardens. These cracks persisted, and recurrent movement along them resulted in dropping the surface of the ground on the side of the cracks toward the oil field. The changes in elevation resulting from these movements amounted to 16 inches or more in places. The movements were accompanied by slight earthquakes which shook the houses, displaced dishes, spilled water, and disturbed the inhabitants generally. Similar faults developed along the southern margin of the oil field on Hogg Island, the displacement here being again downward on the side toward the area of oil extraction, and varying from 3 to 12 inches in vertical extent.



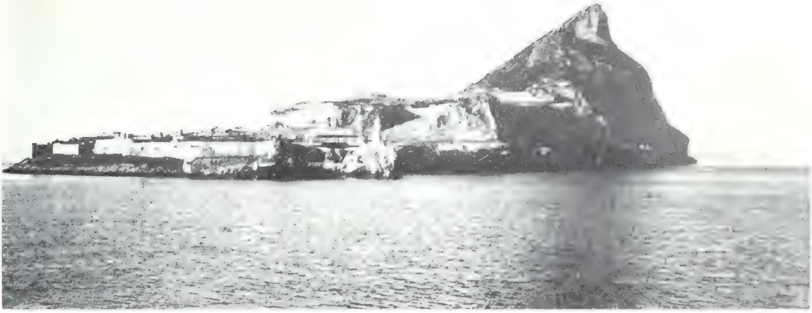
—Journal of Geology

FIG. 5.—GOOSE CREEK REGION AFTER SUBSIDENCE.

Submerged land in Texas belongs to the state and only the state can grant oil and gas leases on submerged lands. Consequently, when Gaillard Peninsula became submerged, the state claimed title to it and sought not only to dispossess the fee owner and the oil and gas lessee, but also to recover from them the value of the oil and gas removed from the premises subsequent to the time when the land became submerged. The question was taken into court and finally decision was rendered in favor of the defendants, that is, the claim of the state of Texas was denied, and the present owners continue in possession. The basis for the decision was the court's acceptance of the contention that the subsidence at Goose Creek (which the defendants admitted) was not the result of natural processes but was caused by an act of man, namely, the removal of large volumes of oil, gas, water, and sand from beneath the surface. No act of man can operate to deprive another man of his property under the law. If the subsidence at Goose Creek had been a natural process, "an act of God," then presumably title to the submerged land would have passed to the state, and property worth millions of dollars would have been lost to the owner of the land and to the operating companies.

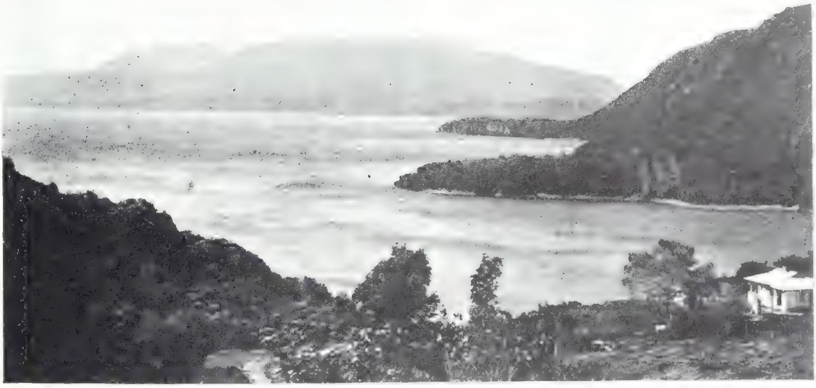
The oil, gas, and water beneath the Goose Creek area are contained in the pore space of unconsolidated sand. In the pumping operations some of the sand has been removed, and the void thus created has been filled by sinking of the material above. But only a slight amount of the sinking is due to this cause. Probably most of the subsidence resulted from compacting of the sand left underground by rearrangement of the individual grains after the fluids were removed from the openings. Some further aspects of the case are considered by the geologists who studied the problem in the field (Pratt and Johnson, 1926, pp. 588-589):

> In our opinion the cause of the subsidence is to be found in the extensive extraction of oil, water, gas, and sand from beneath the affected area. The purely local character of the disturbance, the facts that the area of subsidence coincides with the area of extraction, that the period of sinking coincides with the period of extraction, and that continued extraction is accompanied by continuing subsidence as shown by the latest



A. GIBRALTAR

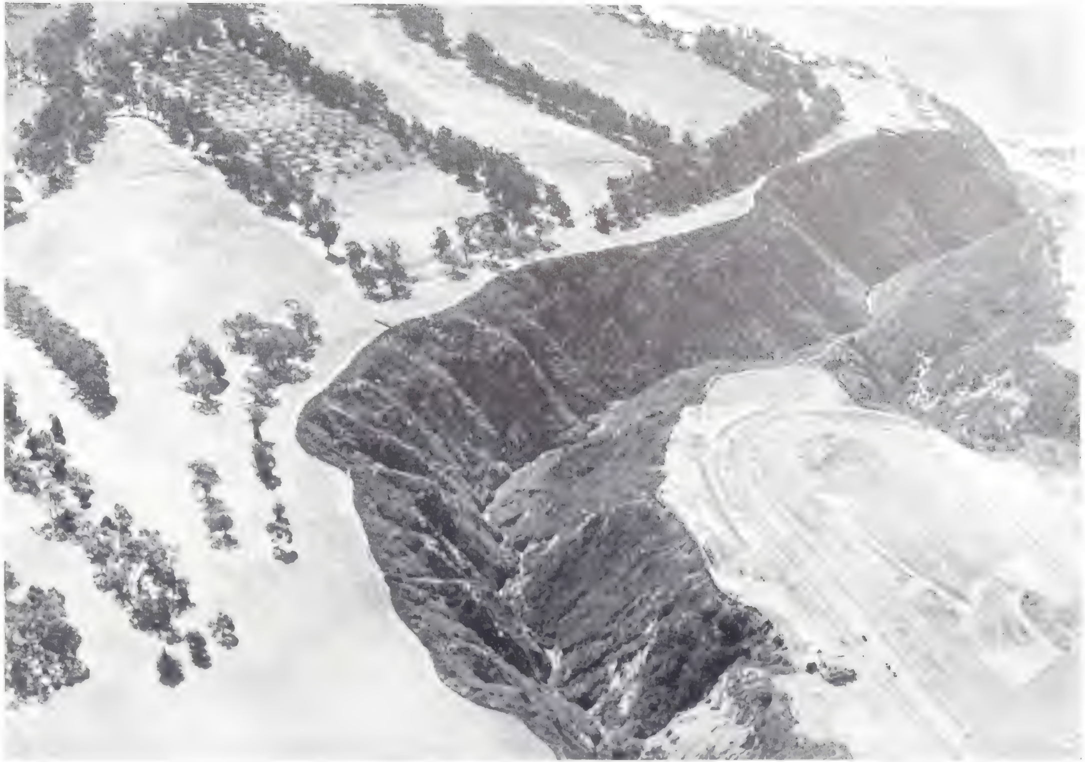
As seen from a steamship entering the strait. Two distinct marine terraces record successive uplifts of the land.



New Zealand Government Publicity Photo

B. LAKE TARAWERA, NEW ZEALAND

Note the terrace cut on the two long spurs, which indicates a former higher stand of the lake water.



U. S. Army Air Corps

CANYON CUTTING A MARINE TERRACE

The smooth surface of this uplifted wave-cut terrace is gashed by a deep young valley that was eroded during and after the uplift. Santa Monica, California.

measurements, all point unmistakably to this conclusion. These points will be considered in order.

It is noticeable that the wells cover an area that is rudely oval, with the longer axis east-west; and the contours of equal subsidence exhibit the same pattern. The center of maximum subsidence is near the center of the drilled area; but the 8-year contours are more closely spaced on the north than on the south, indicating a steeper slope where the wells are most closely grouped, as if slumping were most effective where the greatest amount of material was taken out. The 1-year contours, based on more abundant data, bring out a truly remarkable correlation between the area of subsidence and the area of extraction. . . . The contour showing a subsidence of .10 foot in 1 year, while not tracing exactly the line between few and abundant wells, corresponds so closely with areas of greater extraction, bending outward where the drilling was carried outward, that it is difficult to escape the conclusion that it shows a distinct extension of the subsidence into areas of extended drilling. The location of the earth fractures near the margins of the field, one on the north and one on the south, with the down-drop in each case toward the center of extraction, is highly significant. Surely the coincidence of the area of subsidence with the area of extraction is remarkably close, and implies a causal relationship.

The time of the subsidence corresponds with the time of extraction. Prior to the development of the oil field in 1917 no indications of subsidence appear to have been noted in this area. The low land of Gaillard Peninsula has served as grazing-ground for cattle for nearly a century, and changes in its size or form or elevation would readily be observed; yet none are reported. Maps made before 1850 show the same shore lines as existed in 1917. Then came the opening of the oil field, and a year later the subsidence became evident. In 8 years the change of level amounted to 3 feet, the shore lines were completely altered, much land submerged, and great areas of vegetation killed by salt water. A closer coincidence between time of subsidence and time of extraction could not be imagined.

Continued extraction is accompanied by continuing subsidence. This is made apparent by recent surveys. . . . For this year (1924-25) the maximum subsidence was .25 foot near the center of the field, the amount decreasing outward in all directions until areas of absolute stability were found about the margins of the affected district.

It is safe to say that the aggregate volume of oil, gas (at 1,000 lbs. per square inch pressure), water, and sand removed from Goose Creek since 1917 will exceed 100,000,000 barrels, or about 500,000,000 cubic feet. When this volume is compared with the calculated space between the former surface and the present surface over the Goose Creek oil field, it is found that there is a considerable excess of "volume of removal" over the "volume of subsidence." As a matter of fact, the estimated volume of materials removed from beneath the surface at Goose Creek is nearly five times as large as the calculated volume between the planes representing the present surface and the former surface of the land. In other words, subsidence, to date, has accounted for only about 20 per cent of the total subterranean voids created by the removal of oil, gas, water, and sand.

BIBLIOGRAPHY

Chapter VII—Shorelines

J. W. Gregory, *The Nature and Origin of Fiords.* London: John Murray, 1913, pp. 1-3.

Lewis M. Haupt, *Changes Along the New Jersey Coast.* Geological Survey of New Jersey, Annual Report for 1905, pp. 36, 37, 41, 46-48, 49-50, 78-79.

Douglas W. Johnson, *The Problem of Coast Protection.* Geographical Review, vol. 17, 1927, pp. 135-136.

Sir Charles Lyell, *Principles of Geology.* Ninth Ed., New York: Appleton, 1860, pp. 300-306, 309-311.

Wallace E. Pratt and Douglas W. Johnson, *Local Subsidence of the Goose Creek Oil Field.* Journal of Geology, vol. 34, 1926, pp. 577-582, 588-589.

CHAPTER VIII

SEDIMENTS AND SEDIMENTARY ROCKS

> . . . It is calculated that the mean rate of advance of the delta of the Po on the Adriatic between the years 1200 and 1600 was 25 yards or meters a year, whereas the mean annual gain from 1600 to 1804 was 74 meters.
>
> Adria was a seaport in the time of Augustus, and had, in ancient times, given its name to the gulf; it is now about twenty Italian miles inland. Ravenna was also a seaport, and is now about four miles from the main sea. Yet even before the practice of embankment [1] was introduced, the alluvium of the Po advanced with rapidity on the Adriatic; for Spina, a very ancient city, originally built in the district of Ravenna, at the mouth of a great arm of the Po, was, so early as the commencement of our era, eleven miles distant from the sea.

The significant facts in these short paragraphs (Lyell, 1860, pp. 256-257) emphasize the rate at which the Adriatic Sea is being filled with sediment. This sea is a shallow basin into which several streams discharge their load derived from the slopes of the Alps and the Apennines. It is established clearly that the bottom of the basin has subsided considerably in recent time; but in spite of this deepening tendency the sediments have not only kept the sea shallow—they have actually turned large areas into habitable land. Vast quantities of detritus are brought from the wasting mountains. Man himself has caused the mountain torrents to become more turbid by denuding the slopes of the forest cover which once protected them.

The relation of the Adriatic to the neighboring mountains is an instructive example of the vast changes that occur on the face of the Earth during geologic time. As mountains go, the Alps and Apennines are young. Their serrate peaks are composed in large part of sedimentary strata which contain shells of marine animals, proving that the sites of the present lofty mountains were seas like the Adriatic not so very long ago. Adjacent to those former seas there were highlands, from which rivers carried sand and mud in large quantities. The decomposing rocks from which this ancient detritus was derived had a still older story of their own; but we shall not go back of them now.

---

[1] The building of levees is meant.—Ed. Note.

The floors of those former basins subsided, just as the Adriatic floor is subsiding now, until vast thicknesses of sedimentary strata had accumulated. Then these strata were folded and lifted up, no doubt very slowly; and as they arose to mountain heights the forces of weathering and erosion once more attacked the rock materials, reducing them to bits and carrying them toward the present seas. Through how many cycles of this kind may some of the material have passed since the Earth began?

Lyell (1860, pp. 257-258) gives other significant facts about the filling of the Adriatic:

> But although so many rivers are rapidly converting the Adriatic into land, it appears, by the observations of M. Morlot, that since the time of the Romans, there has been a general subsidence of the coast and bed of this sea in the same region to the amount of five feet, so that the advance of the new-made land has not been so fast as it would have been had the level of the coast remained unaltered. The signs of a much greater depression anterior to the historical period have also been brought to light by an Artesian well, bored in 1847, to the depth of more than 400 feet, which still failed to penetrate through the modern fluviatile deposit. The auger passed chiefly through beds of sand and clay, but at four several depths, one of them very near the bottom of the excavation, it pierced beds of turf, or accumulations of vegetable matter, precisely similar to those now formed superficially on the extreme borders of the Adriatic. Hence we learn that a considerable area of what was once land has sunk down 400 feet in the course of ages.
>
> The greatest depth of the Adriatic, between Dalmatia and the mouths of the Po, is twenty-two fathoms; but a large part

of the Gulf of Trieste and the Adriatic, opposite Venice, is less than twelve fathoms deep. Farther to the south, where it is less affected by the influx of great rivers, the gulf deepens considerably. Donati, after dredging the bottom, discovered the new deposits to consist partly of mud and partly of rock, the rock being formed of calcareous matter, incrusting shells. . . . Olivi, also, found some deposits of sand, and others of mud, extending half way across the gulf; and he states that their distribution along the bottom was evidently determined by the prevailing current. It is probable, therefore, that the finer sediment of all the rivers at the head of the Adriatic may be intermingled by the influence of the current; and all the central parts of the gulf may be considered as slowly filling up with horizontal deposits, similar to those of the Subapennine hills, and containing many of the same species of shells. The Po merely introduces at present fine sand and mud, for it carries no pebbles farther than the spot where it joins the Trebia, west of Piacenza. Near the northern borders of the basin, the Isonzo, Tagliamento, and many other streams, are forming immense beds of sand and some conglomerate; for here some high mountains of Alpine limestone approach within a few miles of the sea.

In the time of the Romans, the hot-baths of Monfalcone were on one of several islands of Alpine limestone, between which and the mainland, on the north, was a channel of the sea, about a mile broad. This channel is now converted into a grassy plain, which surrounds the islands on all sides. Among the numerous changes on this coast, we find that the present channel of the Isonzo is several miles to the west of its ancient bed, in part of which, at Ronchi, the old Roman bridge which crossed the Via Appia was lately found buried in fluviatile silt.

The Adriatic is only one of many basins into which the wasting Alps and related mountains are shedding great quantities of débris. Some of the larger rivers, such as the Rhone, empty their load directly into the Mediterranean. Part of the burden, however, is dropped into settling basins en route. The delta of the Rhone in Lake Geneva is a conspicuous feature, and it is growing at a rapid rate. Lyell (1860, p. 189) predicts the future result:

> The sediment of the Rhone . . . thrown into the Lake of Geneva, is now conveyed to a spot a mile and a half distant from that where it accumulated in the tenth century, and six miles from the point where the delta began originally to form. We may look forward to the period when this lake will be filled up, and then the distribution of the transported matter will be suddenly altered, for the mud and sand brought down from the Alps will thenceforth, instead of being deposited near Geneva, be carried nearly 200 miles southwards, where the Rhone enters the Mediterranean.

We may go a step further, and foretell the final fate of the Geneva sediments if the history of the Rhone continues to its logical conclusion. After the filling of the lake is complete the river will continue to reduce its grade, and eventually its valley will be cut down entirely through the lake deposits. Tributaries and slope wash will then carry these sediments into the river, and they will be transported the rest of the way to the Mediterranean, to become part of the growing delta of the Rhone. Inevitably this will be the succession of events provided the river runs its normal course to old age. Most lakes are temporary settling basins in which sediments rest for a time before completing the full journey to the sea.

The delta at the mouth of the Rhone has changed radically since the time of the Romans (Lyell, 1860, pp. 258-260):

> *Marine Delta of the Rhone.*—The lacustrine delta of the Rhone in Switzerland has already been considered; its contemporaneous marine delta may now be described. Scarcely has the river passed out of the Lake of Geneva before its pure waters are again filled with sand and sediment by the impetuous Arve, descending from the highest Alps, and bearing along in its current the granitic detritus annually brought down by the glaciers of Mont Blanc. The Rhone afterwards receives

vast contributions of transported matter from the Alps of Dauphiny, and the primary and volcanic mountains of Central France; and when at length it enters the Mediterranean, it discolors the blue waters of that sea with a whitish sediment, for the distance of between six and seven miles, throughout which space the current of fresh water is perceptible.

Strabo's description of the delta is so inapplicable to its present configuration, as to attest a complete alteration in the physical features of the country since the Augustan age. It appears, however, that the head of the delta, or the point at which it begins to ramify, has remained unaltered since the time of Pliny, for he states that the Rhone divided itself at Arles into two arms. This is the case at present; one of the branches, the western, being now called Le Petit Rhone, which is again subdivided before entering the Mediterranean. The advance of the base of the delta, in the last eighteen centuries, is demonstrated by many curious antiquarian monuments. The most striking of these is the great and unnatural détour of the old Roman road from Ugernum to Beziers (*Bœterræ*) which went round by Nismes (*Nemausus*). It is clear that, when this was first constructed, it was impossible to pass in a direct line, as now, across the delta, and that either the sea or marshes intervened in a tract now consisting of terra firma. Astruc also remarks, that all the places on low lands, lying to the north of the old Roman road between Nismes and Beziers, have names of Celtic origin, evidently given to them by the first inhabitants of the country; whereas, the places lying south of that road, towards the sea, have names of Latin derivation, and were clearly founded after the Roman language had been introduced.

Another proof, also, of the great extent of land which has come into existence since the Romans conquered and colonized Gaul, is derived from the fact, that the Roman writers never mention the thermal waters of Balaruc in the delta, although they were well acquainted with those of Aix, and others still more distant, and attached great importance to them, as they invariably did to all hot springs. The waters of Balaruc, therefore, must have formerly issued under the sea—a common phenomenon on the borders of the Mediterranean; and on the advance of the delta they continued to flow out through the new deposits.

Among the more direct proofs of the increase of land, we find that Mese, described under the appellation of Mesua Collis by Pomponius Mela, and stated by him to be nearly an island, is now far inland. Notre Dame des Ports, also, was a harbor in 898, but is now a league from the shore. Psalmodi was an island in 815, and is now two leagues from the sea. Several old lines of towers and sea-marks occur at different distances from the present coast, all indicating the successive retreat of the sea, for each line has in its turn become useless to mariners; which may well be conceived, when we state that the Tower of Tignaux, erected on the shore so late as the year 1737, is already a mile remote from it.

By the confluence of the Rhone and the currents of the Mediterranean, driven by winds from the south, sand-bars are often formed across the mouths of the river; by these means considerable spaces become divided off from the sea, and subsequently from the river also, when it shifts its channels of efflux. As some of these lagoons are subject to the occasional ingress of the river when flooded, and of the sea during storms, they are alternately salt and fresh. Others, after being filled with salt water, are often lowered by evaporation till they become more salt than the sea; and it has happened, occasionally, that a considerable precipitate of muriate of soda has taken place in these natural salterns. During the latter part of Napoleon's career, when the excise laws were enforced with extreme vigor, the police was employed to prevent such salt from being used. The fluviatile and marine shells inclosed in these small lakes often live together in brackish water; but the uncongenial nature of the fluid usually produces a dwarfish size, and sometimes gives rise to strange varieties in form and color.

Captain Smyth in his survey of the coast of the Mediterranean, found the sea opposite the mouth of the Rhone, to deepen gradually from four to forty fathoms, within a distance of six or seven miles, over which the discolored fresh water extends; so that the inclination of the new deposits must be too slight to be appreciable in such an extent of section as a geologist usually obtains in examining ancient formations. When the wind blew from the southwest, the ships employed in the survey were obliged to quit their moorings; and when they returned, the new sand-banks in the delta were found covered over with a great abundance of marine shells. By this means, we learn how occasional beds of drifted marine shells may become interstratified with freshwater strata at a river's mouth.

The discussion above gives some idea of the kind of material that is laid down off the mouths of rivers and the conditions of its deposition. We know that in time the soft mud becomes compact shale, and the loose sand changes into firm sandstone; layers of vegetable accumulation, collected in swamps or shallow lakes on the delta and later covered over with mud, change into coal; and throughout the series of consolidated sediments there will be fossil forms of trees and other plants, of land animals that roamed the surface of the delta, and of marine creatures that lived on the muddy or sandy sea floor. Old sedimentary strata with these characteristics are now exposed in many lands, to give us the history of ancient periods. Lyell (1860, pp. 274-275) reminds us that the accumulation, hardening, and uplift of these ancient deltas took place by slow, orderly processes involving immense periods of time:

Before we take leave of the great delta,[1] we may derive an instructive lesson from the reflection that the new deposits already formed, or now accumulating, whether marine or freshwater, must greatly resemble in composition, and the general character of their organic remains, many ancient strata, which enter largely into the earth's structure. Yet there is no sudden revolution in progress, whether on the land or in the waters, whether in the animate or the inanimate world. Notwithstanding the excessive destruction of soil and uprooting of trees, the region which yields a never-failing supply of driftwood is densely clothed with noble forests, and is almost unrivalled in its power of supporting animal and vegetable life. In spite of the undermining of many a lofty bluff and the encroachments of the delta on the sea, in spite of the earthquake, which rends and fissures the soil, or causes areas more than sixty miles in length to sink down several yards in a few months, the general features of the district remain unaltered, or are merely undergoing a slow and insensible change. Herds of wild deer graze on the pastures, or browse upon the trees; and if they diminish in number, it is only where they give way to man and the domestic animals which follow in his train. The bear, the wolf, the fox, the panther, and the wild-cat still maintain themselves in the fastness of the forests of cypress and gum-tree. The racoon and the opossum are everywhere abundant, while the musk-rat, otter, and mink still frequent the rivers and lakes, and a few beavers and buffaloes have not yet been driven from their ancient haunts. The waters teem with alligators, tortoises, and fish, and their surface is covered with millions of migratory waterfowl. . . . Such is the state of a continent where trees and stones are hurried annually by a thousand torrents, from the mountains to the plains, and where sand and finer matter are swept down by a vast current to the sea, together with the wreck of countless forests and the bones of animals which perish in the inundations. When these materials reach the gulf, they do not render the waters unfit for aquatic animals; but on the contrary, the ocean here swarms with life, as it generally does where the influx of a great river furnishes a copious supply of organic and mineral matter. Yet many . . . , when they behold the spoils of the land heaped in successive strata, and blended confusedly with the remains of fishes, or interspersed with broken shells and corals; when they see portions of erect trunks of trees with their roots still retaining their natural position, and one tier of these preserved in a fossil state above another, imagine that they are viewing the signs of a turbulent instead of a tranquil and settled state of the planet. They read in such phenomena the proof of chaotic disorder and reiterated catastrophes, instead of indications of a surface as habitable as the most delicious and fertile districts now tenanted by man.

---

[1] These remarks of Lyell conclude a description of the Mississippi Delta. Ed. Note.

Within the last quarter century the study of sedimentary rocks has been especially extensive and intensive, owing in part to the search for petroleum, coal, and other economic products that occur in these rocks. As a result, knowledge of sediments and of the solid rocks made from them has increased enormously since the time of Lyell. In order to find the keys for unlocking old secrets, modern students dredge the ocean floor at all depths, collect samples of detritus from the various parts of deltas, watch the building of deposits on flood plains, on piedmont slopes, and in sand dunes—in short, attempt to learn the characteristics of every kind of deposit forming at the present time. With this detailed information in mind, it is possible to study an ancient sandstone, shale, or limestone, and learn much about the conditions under which it was formed. Such matters are of more than academic interest. In prospecting for oil, coal, potash, phosphate, and numerous other mineral substances it is important to know whether the sediments that make up the rock were laid down in the sea, in tidal or fresh-water swamps, in desert basins, in river plains, or in some other situation.

Although much valuable information has been acquired only in recent years, Lyell knew the broad general principles of sedimentation and stated them well. The greatest weakness in the eighteenth century teaching lay in the exaggerated importance assigned to marine deposition. Lyell and his contemporaries taught that no extensive sedimentary formation could be formed on the land. In their philosophy, every widespread conglomerate, sandstone, or shale, as well as limestone, represented a former seaway —or at least a large lake—in which the sediments were laid down. With this idea in mind, the old texts commonly refer to all sedimentary rocks as *aqueous* formations. Now we know that many of the ancient coarse-grained sediments represent former alluvial fans or piedmont slopes; that some of the thick sandstones and shales exposed in mountain regions were formed as successive layers on wide flood plains; and that even some limestones originated on the surfaces of arid or semi-arid lands. Moreover, some important formations are now recognized as *eolian* instead of *aqueous* in their origin; and although by far the larger portion of the sediments are in some measure waterlaid, running water on the land has played a very important part as well as seas and lakes.

The thick sandstones and shales deposited during the Triassic period in what is now central Connecticut make a highly interesting study in sedimentation. It is obvious that much of the sand and gravel was produced by disintegration of granite and similar crystalline rocks; because the predominant minerals in the sediments are feldspar, quartz, and mica. The presence of so much fresh feldspar in sediments is unusual, and indicates peculiar conditions which prevented rapid decay of the rock fragments formed by Triassic weathering in this area. This fact was recognized even by the earlier geologists; but in accordance with the prevalent thought, they supposed that the sediments were swept into a seaway which extended northward into Massachusetts. Numerous features of the Triassic rocks refute this belief. Many of the layers retain the patterns of large mud-cracks, which show that the wet sediments were exposed to the air for a considerable time after deposition. Footprints of land animals, prints made by raindrops, and fossils of land plants are common features of the shales and fine-grained sandstones; and fossil remains of fresh-water fishes are numerous in some layers.

Further discussion of these sedimentary rocks, to explain their significance and to picture more clearly the conditions of their formation, cannot be phrased more happily than the following quotation from Davis (1896, pp. 33-37):

> It requires a conscious effort to picture the geographical conditions that must have long prevailed within and around the depressed area in which the strata were accumulated. The bedding planes of the strata, revealed only in scanty exposures in which the Triassic strata are generally worn across their edges, must in imagination be transformed into broad floors of

washed sands and pebbles, derived from a land area on the west or east, and gradually drifted from the margin toward the middle of the trough, where they accumulated. For every grain remaining in a sandstone bed thousands of grains must have gone past it, slowly moved by transporting agencies, slowly worn finer and finer. Every layer seen to-day is more a witness of transportation than of deposition. The sands were not washed directly to their place of settlement and there at once deposited; they were gradually moved along the water floor. The finest silts may have been actually carried in muddy lacustrine waters, but they must have been many times laid down and taken up before finding a final resting place. The coarser beds are to-day generally found near the margin of the formation, on the east or west; but sometimes pebbles or cobbles up to 6 or 8 inches in diameter are found near the medial axis of the lowlands, as north of Meriden. Such strata may be taken to indicate a more than ordinary activity of transporting forces in the middle of the depressed area, probably during a time of encroachment of the coarser marginal deposits on the flatter surface of the finer sediments along the middle of the trough. On the other hand, fine-textured and evenly laminated shales sometimes occur close to the border of the lowland, as in the curves of Pond and Totoket mountains, north of Branford; possibly because of a less active supply of sediments from the adjoining lands.

Every pebble, every grain of sand, every particle of silt, is best understood as having been made in the manner of to-day —detached by weathering from the adjoining land surface and moved downhill in the creeping soil cap, carried down valleys by the wash of streams, or drifted from deltas into shallow lakes. There may have been storms and floods then as now, but there is no sufficient reason for supposing that Triassic time was significantly more unquiet than is the present. As the hills of New England are weathering and wasting before our eyes, as the streams are flowing down their valleys, so can we best picture them on the ancient New England of Triassic time. Only in this deliberate manner must the accumulation of one stratum on another be imagined. Even the coarse bowlders of the marginal conglomerates, such as occur inside of the Pond and Totoket crescents, must have long rolled along the water courses from their source, and must have witnessed the passage of a great volume of finer materials over their heads before they were finally buried.

Cross bedding and ripple marks are among the commonest of the detailed structures in the Triassic strata. Hence we are assured the sediments did not advance by a steady and rapid movement from margin to center, but by an intermittent migration, settling down for a time and perhaps buried to the depth of a foot or more, only to be uncovered and drifted along again in the general line of progress. Deposition, on the whole, prevailed; but at any one point the deposited material can have been only a small residue of the transported material. Ages and ages must have passed, every day of which had its deliberate dawn and close, every year of which must have shown only such minute changes as are now to be witnessed in the wearing down of uplands and in the filling of lowlands; yet in the end the Triassic strata grew to be two miles thick. No just appreciation of this great labor of wasting and building can be gained by rapidly walking across the valley of to-day. The slow changes of the past must be deliberately dwelt upon if they are to be clearly conceived.

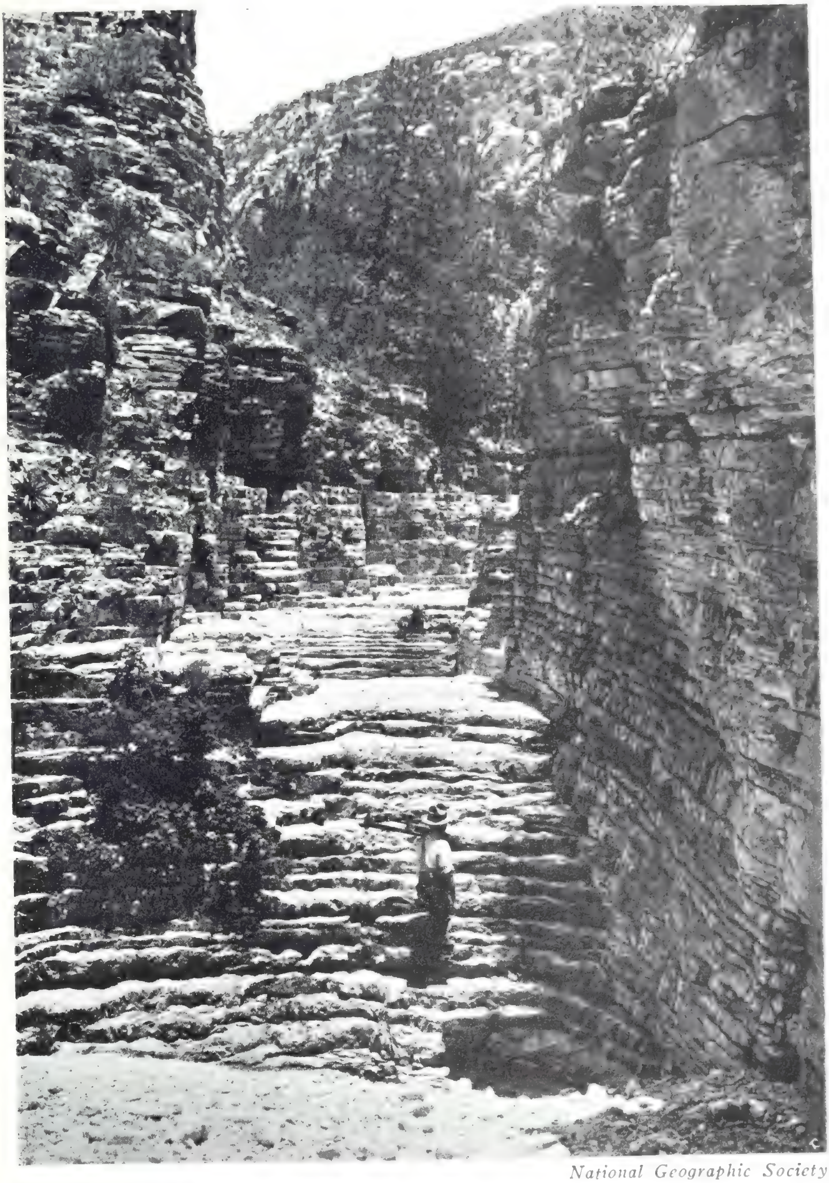
Perhaps the most notable feature of all this time is that, in spite of the great depth of the Triassic basin as measured in the total thickness of its strata, by far the greater number of layers give clear evidence of having been deposited by streams or in comparatively shallow water; thus repeating the geological paradox encountered in many other regions, of a shallow basin always filling and yet never becoming filled. The coarse texture of the sandstones that make so large a share of the whole series of deposits, the cross bedding and ripple marks in the sandstones, the ripple marks, mud cracks, and rain prints in the finer layers, and the innumerable footprints of large and small reptiles in strata at various horizons in the formation are conclusive evidence that where any waters stood they were prevailingly shallow, and that their floor was occasionally laid bare. Yet in these shallow waters strata measuring thousands of feet in thickness were deposited.

The accumulation of a great series of strata under such conditions requires the supposition that a gradual depression of the trough must have been in progress during all the time of deposition. The trough could not have been depressed to its full depth before the deposits began, and then gradually filled to the surface. On the contrary, the depression of its floor must have gone on at about equal rate with the accumulation of sediment, for only in this way could fluviatile and subaerial conditions or shallow waters have been maintained all through the period of deposition. It must be carefully recognized that the depression thus inferred was of the most gradual kind. From the bare term "depression," one might at first gather an idea of subsidence at altogether too rapid a rate, picturing it as advancing visibly. On the contrary, could the process have been watched, it would have wrought no perceptible change from year to year; and if it had been followed from century to century there is sufficient reason for thinking that its effects would not have been more noticeable than are the changes of level on the coast of Scandinavia to-day.

It should not be supposed that there was a perfect uniformity in the rate of depression, and that any irregularity of depression was at once compensated by an equivalent irregularity of deposition; but only that, on the whole, the two processes went on together in a rather equable manner, and that at no time was there a deep submergence. The conglomerate beds north of Meriden are best interpreted as marking the advance of active streams to the middle of the trough and indicating a gain of deposition over depression. The shales near the margin in Branford indicate quieter conditions, but the greater body of sandstones points to a well-preserved balance of the two counteracting processes. From the more permanent inclosing lands, whence the waste was persistently shed, the slopes should be pictured as descending into a shallow trough occupied by broad washes of sand and gravel, crossed by wandering streams. Shallow lakes may have now and then overflowed a middle strip or a greater part of the trough, and there finer sediments would gather. The lake floors were sometimes slowly shoaling, and then invaded by sands and pebbles from the shores; sometimes sinking to greater depth, but tranquil enough to tempt occupation by great numbers of fish, whose forms are still well preserved in the black shale beds near the middle horizons of the formation.

Nothing contributes so vividly to the reality of this picture as the footprints of the reptiles, crossing and recrossing on the sandstones of to-day, the sand flats of the earlier era. . . . The prints are generally of even impression, indicating a leisurely stride, as little hurried as the processes of accumulation. All told, they would be counted by millions; and yet this should not be taken so much as indicating a dense reptilian population as a slow accumulation of strata, and perhaps an industrious search for food by the print makers. So with the fossil fish; they are not often found, because the black shales that contain them, very weak and easily eroded, are commonly worn down in valleys and covered with drift; but they must exist in myriads, for almost wherever opened the black shales bear their skeletons and scales on every few feet of surface. Here every print means an individual, while a hundred thousand tracks may have been made by a single reptile. Hence, in spite of the slower deposit of shales than of sandstones, the fish must have been more plentiful in the shale-forming waters than the reptiles were on the sand flats.

The tracks are commonly found in association with strata that are seamed with cracks, as if dried by exposure to air and sunshine, cracks of this kind being often formed at times of low water on the bed or flood plain of aggrading, wandering rivers. Marshes of reeds and ferns must have flourished on the lowlands, and forests of an antique flora must have grown



National Geographic Society

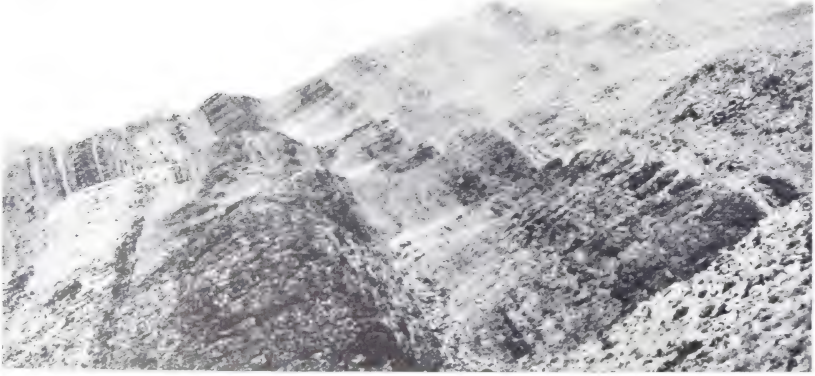
STAIRS OF PINE CANYON

Layers of sedimentary rock eroded to resemble a staircase. New Mexico.

Geol. Surv. of England and Wales

A. BREAKING TO PIECES AGAIN

An old conglomerate exposed to attack by the waves. The resulting sediments are deposited in the sea, and eventually will become sedimentary rock again.



B. FROM SEA TO DESERT

Marine limestone and shale, tilted steeply and eroded. Desert Range, southern Nevada.

on the surrounding hills, for many prints of land plants, large and small, are found in the shale beds. The forests and the marshes, the uplands and the streams of the trough, received the rain of passing showers, but the raindrops made a lasting record only now and then, when a fitting surface caught their dimpled marks and a gentle overflow quickly covered them with sediment. Not the showers themselves, but the chance of preserving their slight record, was the rarity; and so to-day, not the surface covered by these and other ancient records, but the chance of seeing them is exceptional. When a stratum is stripped along a bedding plane, as happens now and then in the quarries, the surface should be in imagination restored to its initial horizontal position, extended far and wide over the floor of the trough, with more pebbles toward the nearer shore and more fine silt the other way, and thus pictured it should be deliberately contemplated. No hurried changes should be introduced, but, as waste weathers, creeps, and washes from the land on which we live to-day, as sediments now grow on flood plains and shallow water floors with the slow-coming waste from the lands, as sea floors subsiding to-day gradually bring about changes of depth and currents faintly noticed from century to century, so in the older times did wearing, washing, and sinking advance with the utmost deliberation. The Triassic scene would have appeared unchanged from day to day, and hardly changed from year to year; it shifted slowly through the countless centuries of filling and sinking. These centuries we are too prone to pass over unconsidered when crossing in an afternoon's stroll the worn edges of the uncounted leaves in this ancient book, whose pages, covered with their slowly written records, are here and there exposed in little patches to our view.

So much attention has been given to sediments formed on continents or in deltas in order to emphasize the importance of such deposits. It is true that the ideal goal of all water-borne sediment is the sea; but in course of time great volumes of detritus have been arrested and converted into solid rock before reaching this final destination. The Triassic sandstones of Connecticut illustrate only one of the general conditions under which these *continental* sediments may accumulate.

Mud deposits on the slope of a delta reach far out and blend with the great blanket of mud that is building up on the continental platform. These muds, forming over vast areas of the sea floors adjacent to continents, are potential shales; and no doubt some of them will be exposed to view by crustal upwarping of the future. A dredge or a sounding apparatus lowered from a ship brings up a sample of the soft sediment. Normally a series of such soundings taken from the shore outward reveals a gradual change from near-shore gravel and sand into fine clays, which in turn give place to light-colored limy muds with increasing distance from land. But of course the succession varies greatly from place to place according to the height of the coast, presence or absence of large rivers to furnish sediment, width of the continental platform, character of currents, and numerous other factors. In warm shallow seas adjacent to low lands, as about the coasts of Florida and the Bahama Islands, the white limy deposits form in vast quantities right up to the shore. Around the Bahama Bank the waves, breaking on the shallow bottom, stir up these sediments and keep the water as white as milk.

One type of the white calcareous sediments which make the widespread "snowfields" on the ocean floor is discussed in a famous essay by Huxley (1897, pp. 5-13, 24-28):

On a Piece of Chalk

The language of the chalk is not hard to learn, not nearly so hard as Latin, if you only want to get at the broad features of the story it has to tell; and I propose that we now set to work to spell that story out together.

We all know that if we "burn" chalk the result is quicklime. Chalk, in fact, is a compound of carbonic acid gas, and lime, and when you make it very hot the carbonic acid flies away and the lime is left. By this method of procedure we see the lime, but we do not see the carbonic acid. If, on the other hand, you were to powder a little chalk and drop it into a good deal of strong vinegar, there would be a great bubbling and fizzing, and, finally, a clear liquid, in which no sign of chalk would appear. Here you see the carbonic acid in the bubbles; the lime, dissolved in the vinegar, vanishes from sight. There are a great many other ways of showing that chalk is essentially nothing but carbonic acid and quicklime. Chemists enunciate the result of all the experiments which prove this, by stating that chalk is almost wholly composed of "carbonate of lime."

It is desirable for us to start from the knowledge of this fact, though it may not seem to help us very far towards what we seek. For carbonate of lime is a widely-spread substance, and is met with under very various conditions. All sorts of limestones are composed of more or less pure carbonate of lime. The crust which is often deposited by waters which have drained through limestone rocks, in the form of what are called stalagmites and stalactites, is carbonate of lime. Or, to take a more familiar example, the fur on the inside of a tea-kettle is carbonate of lime; and, for anything chemistry tells us to the contrary, the chalk might be a kind of gigantic fur upon the bottom of the earth-kettle, which is kept pretty hot below.

Let us try another method of making the chalk tell us its own history. To the unassisted eye chalk looks simply like a very loose and open kind of stone. But it is possible to grind a slice of chalk down so thin that you can see through it—until it is thin enough, in fact, to be examined with any magnifying power that may be thought desirable. A thin slice of the fur of a kettle might be made in the same way. If it were examined microscopically, it would show itself to be a more or less distinctly laminated mineral substance, and nothing more.

But the slice of chalk presents a totally different appearance when placed under the microscope. The general mass of it is made up of very minute granules; but, imbedded in this matrix, are innumerable bodies, some smaller and some larger, but, on a rough average, not more than a hundredth of an inch in diameter, having a well-defined shape and structure. A cubic inch of some specimens of chalk may contain hundreds of thousands of these bodies, compacted together with incalculable millions of the granules.

The examination of a transparent slice gives a good notion of the manner in which the components of the chalk are arranged, and of their relative proportions. But, by rubbing up some chalk with a brush in water and then pouring off the milky fluid, so as to obtain sediments of different degrees of fineness, the granules and the minute rounded bodies may be pretty well separated from one another, and submitted to microscopic examination, either as opaque or as transparent objects. By combining the views obtained in these various methods, each of the rounded bodies may be proved to be a beautifully constructed calcareous fabric, made up of a number of chambers, communicating freely with one another. The chambered bodies are of various forms. One of the commonest is something like a badly-grown raspberry, being formed of a number of nearly globular chambers of different sizes congregated together. It is called *Globigerina,* and some specimens of chalk consist of little else than *Globigerinæ* and granules. Let us fix our attention upon the *Globigerina.* It is the spoor of the game we are tracking. If we can learn what it is and what are the conditions of its existence, we shall see our way to the origin and past history of the chalk.

A suggestion which may naturally enough present itself is, that these curious bodies are the result of some process of aggregation which has taken place in the carbonate of lime; that, just as in winter, the rime on our windows simulates the most delicate and elegantly arborescent foliage—proving that the mere mineral water may, under certain conditions, assume the outward form of organic bodies—so this mineral substance, carbonate of lime, hidden away in the bowels of the earth, has taken the shape of these chambered bodies. I am not raising a merely fanciful and unreal objection. Very learned men, in former days, have even entertained the notion that all the formed things found in rocks are of this nature; and if no such conception is at present held to be admissible, it is because long and varied experience has now shown that mineral matter never does assume the form and structure we find in fossils. If any one were to try to persuade you that an oyster-shell (which is also chiefly composed of carbonate of lime) had crystallized out of sea-water, I suppose you would laugh at the absurdity. Your laughter would be justified by the fact that all experience tends to show that oyster-shells are formed by the agency of oysters, and in no other way. And if there were no better reasons, we should be justified, on like grounds, in believing that *Globigerina* is not the product of anything but vital activity.

Happily, however, better evidence in proof of the organic nature of the *Globigerinæ* than that of analogy is forthcoming. It so happens that calcareous skeletons, exactly similar to the *Globigerinæ* of the chalk, are being formed, at the present moment, by minute living creatures, which flourish in multitudes, literally more numerous than the sands of the sea-shore, over a large extent of that part of the earth's surface which is covered by the ocean.

The history of the discovery of these living *Globigerinæ,* and of the part which they play in rock building, is singular enough. It is a discovery which like others of no less scientific importance, has arisen, incidentally, out of work devoted to very different and exceedingly practical interests. When men first took to the sea, they speedily learned to look out for shoals and rocks; and the more the burthen of their ships increased, the more imperatively necessary it became for sailors to ascertain with precision the depth of the waters they traversed. Out of this necessity grew the use of the lead and sounding line; and, ultimately, marine-surveying, which is the recording of the form of coasts and of the depth of the sea, as ascertained by the sounding-lead, upon charts.

At the same time, it became desirable to ascertain and to indicate the nature of the sea-bottom, since this circumstance greatly affects its goodness as holding ground for anchors. Some ingenious tar, whose name deserves a better fate than the oblivion into which it has fallen, attained this object by "arming" the bottom of the lead with a lump of grease, to which more or less of the sand or mud, or broken shells, as the case might be, adhered, and was brought to the surface. But, however well adapted such an apparatus might be for rough nautical purposes, scientific accuracy could not be expected from the armed lead, and to remedy its defects (especially when applied to sounding in great depths) Lieut. Brooke, of the American Navy, some years ago invented a most ingenious machine, by which a considerable portion of the superficial layer of the sea-bottom can be scooped out and brought up from any depth to which the lead descends. In 1853, Lieut. Brooke obtained mud from the bottom of the North Atlantic, between Newfoundland and the Azores, at a depth of more than 10,000 feet, or two miles, by the help of this sounding apparatus. The specimens were sent for examination to Ehrenberg of Berlin, and to Bailey of West Point, and those able microscopists found that this deep-sea mud was almost entirely composed of the skeletons of living organisms—the greater proportion of these being just like the *Globigerinæ* already known to occur in the chalk.

Thus far, the work had been carried on simply in the interests of science, but Lieut. Brooke's method of sounding acquired a high commercial value, when the enterprise of laying down the telegraph-cable between this country and the United States was undertaken. For it became a matter of immense importance to know, not only the depth of the sea over the whole line along which the cable was to be laid, but the exact nature of the bottom, so as to guard against chances of cutting or fraying the strands of that costly rope. The Admiralty consequently ordered Captain Dayman, an old friend and shipmate of mine, to ascertain the depth over the whole line of the cable, and to bring back specimens of the bottom. In former days, such a command as this might have sounded very much like one of the impossible things which the young Prince in the Fairy Tales is ordered to do before he can obtain the hand of the Princess. However, in the months of June and July, 1857, my friend performed the task assigned to him with great expedition and precision, without, so far as I know, having met with any reward of that kind. The specimens of Atlantic mud which he procured were sent to me to be examined and reported upon.

The result of all these operations is, that we know the contours and the nature of the surface-soil covered by the North Atlantic for a distance of 1,700 miles from east to west, as well as we know that of any part of the dry land. It is a prodigious plain—one of the widest and most even plains in the world. If the sea were drained off, you might drive a waggon all the way from Valentia, on the west coast of Ireland, to Trinity Bay, in Newfoundland. And, except upon one sharp incline about 200 miles from Valentia, I am not quite sure that it would even be necessary to put the skid on, so gentle are the ascents and descents upon that long route. From Valentia the road would lie down-hill for about 200 miles to the point at which the bottom is now covered by 1,700 fathoms of sea-water. Then would come the central plain, more than a thousand miles wide, the inequalities of the surface of which would be hardly perceptible, though the depth of water upon it now varies from 10,000 to 15,000 feet; and there are places in which Mont Blanc might be sunk without showing its peak above water. Beyond this, the ascent on the American side commences, and gradually leads, for about 300 miles, to the Newfoundland shore.

Almost the whole of the bottom of this central plain (which extends for many hundred miles in a north and south direction) is covered by a fine mud, which, when brought to the surface, dries into a grayish white friable substance. You can write with this on a blackboard, if you are so inclined; and, to the eye, it is quite like very soft, grayish chalk. Examined chemically, it proves to be composed almost wholly of carbonate of lime; and if you make a section of it, in the same way as that of the piece of chalk was made, and view it with the microscope, it presents innumerable *Globigerinæ* embedded in a granular matrix. Thus this deep-sea mud is substantially chalk. I say substantially, because there are a good many minor differences; but as these have no bearing on the question immediately before us,—which is the nature of the *Globigerinæ* of the chalk,—it is unnecessary to speak of them.

Thus, not only is it certain that the chalk is the mud of an ancient sea-bottom; but it is no less certain, that the chalk sea existed during an extremely long period, though we may not be prepared to give a precise estimate of the length of that period in years. The relative duration is clear, though the absolute duration may not be definable. The attempt to affix any precise date to the period at which the chalk sea began, or ended, its existence, is baffled by difficulties of the same kind. But the relative age of the Cretaceous epoch may be determined with as great ease and certainty as the long duration of that epoch.

You will have heard of the interesting discoveries recently made, in various parts of Western Europe, of flint implements, obviously worked into shape by human hands, under circumstances which show conclusively that man is a very ancient denizen of these regions. It has been proved that the whole populations of Europe, whose existence has been revealed to us in this way, consisted of savages, such as the Esquimaux are now; that, in the country which is now France, they hunted the reindeer, and were familiar with the ways of the mammoth and the bison. The physical geography of France was in those days different from what it is now—the river Somme, for instance, having cut its bed a hundred feet deeper between that time and this; and, it is probable, that the climate was more like that of Canada or Siberia, than that of Western Europe.

The existence of these people is forgotten even in the traditions of the oldest historical nations. The name and fame of them had utterly vanished until a few years back; and the amount of physical change which has been effected since their day renders it more than probable that, venerable as are some of the historical nations, the workers of the chipped flints of Hoxne or of Amiens are to them, as they are to us, in point of antiquity. But, if we assign to these hoar relics of long-vanished generations of men the greatest age that can possibly be claimed for them, they are not older than the drift, or boulder clay, which, in comparison with the chalk, is but a very juvenile deposit. You need go no further than your own sea-board for evidence of this fact. At one of the most charming spots on the coast of Norfolk, Cromer, you will see the boulder clay forming a vast mass, which lies upon the chalk, and must consequently have come into existence after it. Huge boulders of chalk are, in fact, included in the clay, and have evidently been brought to the position they now occupy by the same agency as that which has planted blocks of syenite from Norway side by side with them.

The chalk, then, is certainly older than the boulder clay. If you ask how much, I will again take you no further than the same spot upon your own coasts for evidence. I have spoken of the boulder clay and drift as resting upon the chalk. That is not strictly true. Interposed between the chalk and the drift is a comparatively insignificant layer, containing vegetable matter. But that layer tells a wonderful history. It is full of stumps of trees standing as they grew. Fir-trees are there with their cones, and hazel-bushes with their nuts; there stand the stools of oak and yew trees, beeches and alders. Hence this stratum is appropriately called the "forest-bed."

It is obvious that the chalk must have been upheaved and converted into dry land, before the timber trees could grow upon it. As the bolls of some of these trees are from two to three feet in diameter, it is no less clear that the dry land thus formed remained in the same condition for long ages. And not only do the remains of stately oaks and well-grown firs testify to the duration of this condition of things, but additional evidence to the same effect is afforded by the abundant remains of elephants, rhinoceroses, hippopotamuses, and other great wild beasts, which it has yielded to the zealous search of such men as the Rev. Mr. Gunn. When you look at such a collection as he has formed, and bethink you that these elephantine bones did veritably carry their owners about, and these great grinders crunch, in the dark woods of which the forest-bed is now the only trace, it is impossible not to feel that they are as good evidence of the lapse of time as the annual rings of the tree stumps.

Thus there is a writing upon the wall of cliffs at Cromer, and whoso runs may read it. It tells us, with an authority which cannot be impeached, that the ancient sea-bed of the chalk sea was raised up, and remained dry land, until it was covered with forest, stocked with the great game the spoils of which have rejoiced your geologists. How long it remained in that condition cannot be said; but "the whirligig of time brought its revenges" in those days as in these. That dry land, with the bones and teeth of generations of long-lived elephants, hidden away among the gnarled roots and dry leaves of its ancient trees, sank gradually to the bottom of the icy sea, which covered it with huge masses of drift and boulder clay. Sea-beasts, such as the walrus, now restricted to the extreme north, paddled about where birds had twittered among the topmost twigs of the fir-trees. How long this state of things endured we know not, but at length it came to an end. The upheaved glacial mud hardened into the soil of modern Norfolk. Forests grew once more, the wolf and the beaver replaced the reindeer and the elephant; and at length what we call the history of England dawned.

Thus you have, within the limits of your own country, proof that the chalk can justly claim a very much greater antiquity than even the oldest physical traces of mankind. But we may go further and demonstrate, by evidence of the same authority as that which testifies to the existence of the father of men, that the chalk is vastly older than Adam himself. The Book of Genesis informs us that Adam, immediately upon his creation, and before the appearance of Eve, was placed in the Garden of Eden. The problem of the geographical position of Eden has greatly vexed the spirits of the learned in such matters, but there is one point respecting which, so far as I know, no commentator has ever raised a doubt. This is, that of the four rivers which are said to run out of it, Euphrates and Hiddekel are identical with the rivers now known by the names of Euphrates and Tigris. But the whole country in which these mighty rivers take their origin, and through which they run, is composed of rocks which are either of the same age as the chalk, or of later date. So that the chalk must not only have been formed, but, after its formation, the time required for the deposit of these later rocks, and for their upheaval into dry land, must have elapsed, before the smallest brook which feeds the swift stream of "the great river, the river of Babylon," began to flow.

Man, the great meddler with the things of Nature, is having an appreciable effect on the rate at which sediments are being carried and deposited. The result of cutting and otherwise destroying a protective forest cover has been referred to in connection with the delta of the Po. Cultivation of the soil increases erosion; great areas of hill land have been made practically worthless in a century or less by loss of the top soil. Of course this sediment finds its way into the rivers and swells the deposits made on flood plains and deltas.

One of the most striking illustrations of man's influence on erosion and sedimentation is furnished by the history of placer mining in California, starting with the famous gold rush of 1849. By digging up and washing the stream gravel and sand on the slope of the Sierra Nevada, the miners started millions of tons of rock débris on its way to the lower country. This unusual stimulus to erosion overloaded the streams, and caused them to spread great sheets of sand, gravel, and silt over previously fertile valley lands. The finer particles were swept onward to the Bay of San Francisco, and were either spread over the floor of the bay or swept out by the tides through the Golden

Gate. Thus an indirect result of the mining operations was to modify the shoreline and swell the volume of marine deposits.

Gilbert, of the U. S. Geological Survey, studied these recent deposits along the entire route from the mountains to the sea. An unexpected outcome of this study is explained by Davis (1927, pp. 272-273):

> Who could have expected, when the investigation of the hydraulic-mining débris was begun, that it would have to include a study of the changes in San Francisco Bay and in the tidal bar outside of the Golden Gate! Yet by following the advance of the débris farther and farther along its course, Gilbert showed most clearly that, contemporaneously with, and therefore presumably in consequence of, the deposition of débris in the head branches of San Francisco Bay, a shoreward shift of the bar has taken place. His argument proceeds as follows: the facts concerning the bar are first assembled. It is semicircular in plan, curving with a radius of 5 miles around a center in Golden Gate; it is formed of detritus detached from the ocean coast, close along which it is drifted by waves and currents, but on reaching the Gate it is held offshore by the ebbing tide. The depth of water on the bar is now 6 fathoms; in the Gate 50 fathoms. Possible changes in the bar are next inquired into. If there were no ebb tide, the bar would stretch directly across the entrance to the Gate as a shoal or beach, in line with the coast beaches to the north and south, and San Francisco Bay would be closed; hence if the present tidal currents in the Gate are weakened, the curve of the bar ought to diminish in radius and the depth of the bar ought to decrease. The relation of tidal currents to bay-head débris is then examined. In so far as the débris merely shoals the bay it has no effect on tidal currents in the Golden Gate; but in so far as it raises the bay bottom above low-tide level in deltas and mud flats, it must weaken the tidal currents; and in so far as delta marshes are reclaimed for agriculture by building dikes to exclude high-tide overflow, the tidal currents at the Gate must be still further weakened.

The actual conditions are then determined. The quantity of detritus washed into the bay-head branches between 1849 and 1914 from natural sources of supply in all parts of the drainage basin as well as from hydraulic mining in the Sierra is estimated at 1,146,000,000 cubic yards—a quantity almost as great as the total outwash from the mines between 1850 and 1884—and this has sufficed to fill some 13,000 acres of bay-branch heads above low-tide level. The diminution of the bay area thus brought about is calculated to reduce the tidal volume in the Golden Gate by 2.5 per cent of its measure in 1850, while the reduction due to the reclamation of tide marshes must amount to an additional 1.5 per cent. The total reduction of the tidal currents from their former value must therefore be about 4 per cent, and it is thought that such a reduction should have a recognizable effect in the shifting of the semi-circular tidal bar. The argument closes by an examination of the position of the bar as shown by Coast Survey charts in 1855, 1873, and 1900. The discovery is thus made that in each interval between surveys the crest of the bar migrated landward, the total change being nearly or quite 1,000 feet; but no loss of depth was demonstrated. As the expectable loss of depth would be only about half a foot for a shoreward shift of 1,000 feet, the failure to detect so small a change is not held to invalidate the conclusion that the recent inward migration of the bar is actually due in large part to deposition of hydraulic-mining and other débris in the bay-heads, and that the remaining part is due to reclamation of the marsh lands. Could there be imagined a more beautiful enchainment of argumentation, or a more convincing demonstration of the principle announced in the Henry Mountains report years before, regarding the "interdependence of drainage lines"!

Now that the key to interpreting the character of sedimentary rocks has been furnished by the painstaking studies of many men, it is relatively easy to see the meaning of a section as simple as that exposed in the Grand Canyon of Arizona. Visitors ordinarily reach the scenic chasm either at El Tovar on the south rim or at Bright Angel on the north. In either case the approach leads across the nearly even surface of a high plateau, where only a few scattered volcanic peaks present any contrast to the horizontal lines that dominate the landscape. In the canyon itself the horizontal element is conspicuous. From the flat plateau surface at the outer rim the descent is by a set of gigantic steps, each formed on hardened layers of ancient sea deposits, to the granite gorge that confines Colorado River. In spite of the rugged features about him, the observant visitor sees much that is orderly and simple. The horizontal strata on which he stands can be projected across to the edges of identical strata miles away in the opposite wall. In general outline the history of the canyon is clear. The wide plateau surface has been lifted, with astonishing uniformity, more than a mile above its former level, and the river has cut away hundreds of cubic miles of solid rock to form a valley in the uplifted mass. And each layer of rock exposed in the walls represents the widespread floor of an ancient sea or a coastal plain that bordered a land of low relief.

But what of the pioneers whose labors furnished the key which we use so successfully? More than a century ago a Scotchman, James Hutton, stated principles that now appear self-evident; but in his day the ideas were doubted by many of his fellow scientists. Some of these principles, as set down by Hutton's friend, Playfair (1822, pp. 22-26) have a large historical interest:

> 1. It is well known that, on removing the loose earth which forms the immediate surface of the land, we come to the solid rock, of which a great proportion is found to be regularly disposed in strata, or beds of determinate thickness, inclined at different angles to the horizon, but separated from one another by equidistant superficies, that often maintain their parallelism to a great extent. These strata bear such evident marks of being deposited by water, that they are universally acknowledged to have had their origin at the bottom of the sea; and it is also admitted, that the materials which they consist of, were then either soft, or in such a state of comminution and

separation, as rendered them capable of arrangement by the action of the water in which they were immersed. Thus far most of the theories of the earth agree; but from this point they begin to diverge, and each to assume a character and direction peculiar to itself. Dr. Hutton's does so, by laying down this fundamental proposition, That in all the strata we discover proofs of the materials having existed as elements of bodies, which must have been destroyed before the formation of those of which these materials now actually make a part.

2. The calcareous strata are the portion of the mineral kingdom that gives the clearest testimony to the truth of this assertion. They often contain shells, corals, and other exuviæ of marine animals in so great abundance, that they appear to be composed of no other materials. Though these remains of organized bodies are now converted into stone or into spar, their shape and interior structure are often so well preserved, that the species of animal or plant of which they once made a part, can still be distinguished and pointed out among the living inhabitants of the ocean.

3. The same conclusions result from an examination of the siliceous strata; under which we may comprehend the common sandstone, and also those pudding-stones or breccias where the gravel consists of quartz. In all these instances, it is plain, that the sand or gravel existed in a state quite loose and unconnected, at the bottom of the sea, previous to its consolidation into stone. But such bodies of gravel or sand could only be formed from the attrition of large masses of quartz, or from the dissolution of such sandstone strata as exist at present; for it will hardly be alleged, that sand is a crystallization of quartz, formed from that substance, when it passes from a fluid to a solid state.

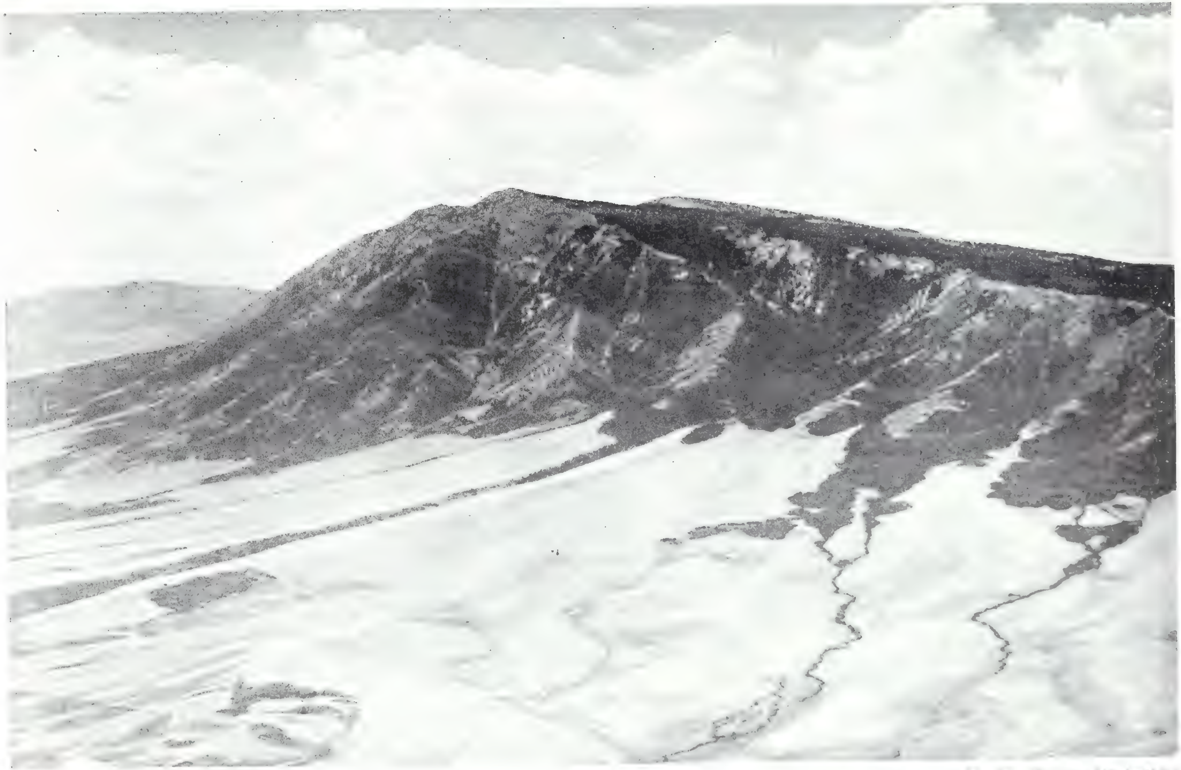
Those pudding-stones in which the gravel is round and polished, carry the conclusions still farther, as such gravel can only be formed in the beds of rivers or on the shores of the sea; for, in the depths of the ocean, though currents are known to exist, yet there can be no motion of the water sufficiently rapid to produce the attrition required to give a round figure and smooth surface to hard and irregular pieces of stone. There must have existed, therefore, not only a sea, but continents, previously to the formation of the present strata.

The same thing is clearly shown by those petrifactions of wood, where, though the vegetable structure is perfectly preserved, the whole mass is siliceous, and has, perhaps, been found in the heart of some mountain, deep imbedded in the solid rock.

4. Characters of the same import are also found among the argillaceous strata, though perhaps more rarely than among the calcareous or siliceous. Such are the impressions of the leaves and stems of vegetables; also the bodies of fish and amphibious animals, found very often in the different kinds of argillaceous schistus, and in most instances having the figure accurately preserved, but the substance of the animal replaced by clay or pyrites. These are all remains of ancient seas or continents; the latter of which have long since disappeared from the surface of the earth, but have still their memory preserved in those archives, where nature has recorded the revolutions of the globe.

5. Among bituminous bodies, pit-coal is the only one which constitutes regular and extensive strata; and no fossil has its origin from the waste of former continents, marked by stronger and more distinct characters. Not to mention that the coal strata are alternated with those that have been already enumerated, and that they often contain shells and corals, perfectly mineralized, it is sufficient to remark, that there are entire beds of this fossil, which appear to consist wholly of wood, and in which the fibrous structure is perfectly preserved. From these instances, the appearances of vegetable structure may be traced through all possible gradations, down to an evanescent state. This last state is undoubtedly the most common; and though coal does not then, on bare inspection, make known its vegetable origin; yet, if we take it in connection with the other terms of the series, as we may call them; if we consider

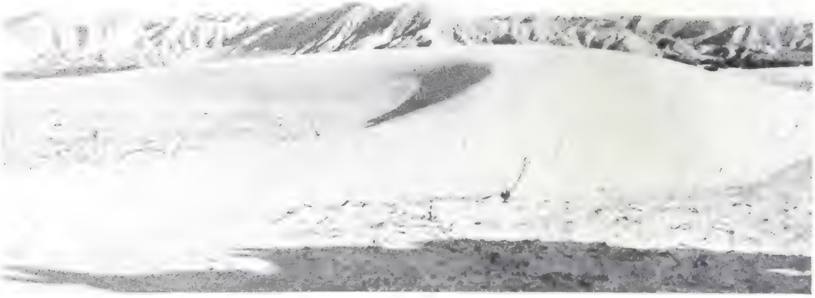
PLATE XXIV



U. S. Army Air Corps

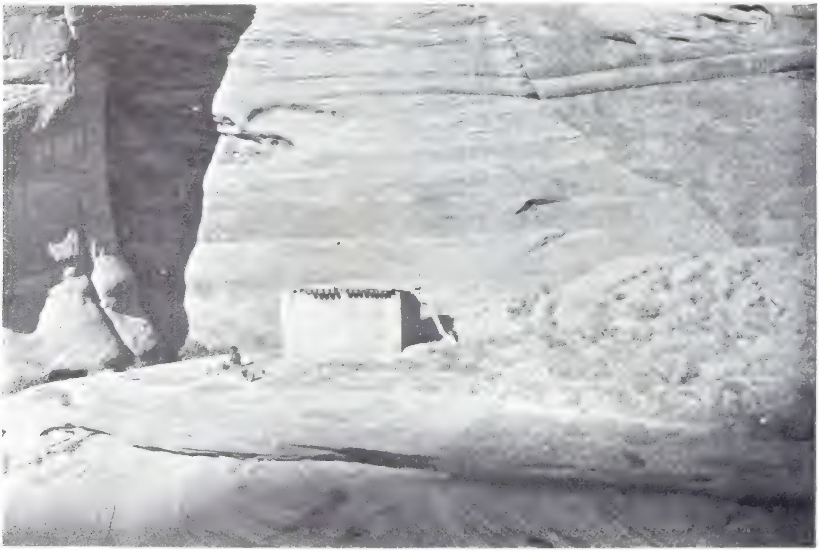
EROSION AND DEPOSITION

Piedmont slope built up by detritus eroded from the Medicine Bow range, Wyoming.



A. A BARCHANE

Crescentic sand dune in Virgin Valley, southern Nevada. Prevailing wind is from right to left.



National Geographic Society

B. CANYON DEL MUERTO

An Indian dwelling on a sandstone bench. The rock is consolidated dune sand of an ancient period. Note large-scale cross-bedding. New Mexico.

that the two extremes, viz., coal, with the vegetable structure perfect, and coal without any such structure visible, are often found in the same or in contiguous beds; and if we remark that through all these gradations coal contains nearly the same chemical elements, and yields, on analysis, bitumen and charcoal, combined with a greater or less proportion of earth: if we take all these circumstances into account, we cannot doubt that this fossil is everywhere the same, and derives its origin from the trees and plants that grew on the surface of the earth before the formation of the present land.

Thus the sedimentary rocks of many dates which, in their present eroded state, form a "ragged pellicle" on the surface of the continents, constitute a vast and authoritative book of facts. In reading this book we do not have to allow for any bias on the part of the author. The facts are absolute; and when we put them together they relate the history of the Earth through long ages. The deposition of sediments now in progress is simply the writing of the latest chapter in the story.

BIBLIOGRAPHY

Chapter VIII—Sediments and Sedimentary Rocks

W. M. Davis, *The Triassic Formation of Connecticut.* U. S. Geological Survey, 18th Annual Report, 1896-97, pp. 33-37.

———, *Grove Karl Gilbert.* Washington: National Academy of Sciences, vol. 21, Fifth Memoir, 1927, pp. 272-273.

Thomas H. Huxley, *Discourses Biological and Geological.* New York: D. Appleton and Company, 1897, pp. 5-13, 24-28.

Sir Charles Lyell, *Principles of Geology.* Ninth Ed., New York: Appleton, 1860, pp. 189, 256-260, 274-275.

John Playfair, *The Works of John Playfair.* Edinburgh: 1822, vol. 1, pp. 22-26.

CHAPTER IX

VOLCANOES AND VOLCANISM

Rome, Nov. 6 [1928].—Mount Etna to-day appears to have sealed the fate of Mascali and other towns on the eastern coast of Sicily. Pushed forward slowly but inexorably by millions of tons of liquid lava vomited by the eruptive craters high up near the volcano's summit, a great, fiery river looking like a gigantic slab of white-hot steel has reached the outskirts of Mascali.

Nothing but a miracle can save it now. It is expected that within a few hours nothing will be left of Mascali, a small but flourishing town of about 10,000 inhabitants.

To make the situation even worse the other stream of lava that stopped yesterday, after swallowing up the first few houses of Santalfio, began moving seaward again to-day. This renders the destruction of Santalfio almost certain and carries Mount Etna's threat to the very doors of the more important town of Giarre.

Mount Etna, "the chimney of Vulcan's forge," is a link that ties us closely to classical antiquity. More than this, it is a living reminder that the forces which have operated through geologic ages to change the face of the Earth are as active to-day as ever; and that we are witnesses, during the brief span of a lifetime, to a few short scenes in a continuous drama which involves the birth and death of mountains, the moving of continental shorelines, and the eventual shifting of entire landscapes.

Volcanoes are among the most fascinating as well as the most terrifying things in nature. In ancient times they were regarded with superstitious awe, because the source of their destructive power was wholly mysterious. Even to-day, in spite of specific studies that have been devoted to volcanoes, as well as the understanding that has come with the general progress of scientific knowledge, the fundamental cause of volcanism is one of the great enigmas of geology. From a geologic as well as a popular viewpoint, however, a volcanic eruption is an extremely attractive event. By watching the flow and congealing of lavas we may see igneous rocks actually in the making. The heat, the explosive violence, and the geographic relations of volcanoes constitute valuable evidence as to hidden conditions beneath the surface; and continued study of these peculiarities promises to yield many additional facts about the Earth.

The press despatch quoted above (Cortesi, 1928), typical of newspaper accounts by which we were able to follow the most recent activity of Etna, pictures intimately the relation of modern volcanism to human affairs. Dwellers in nonvolcanic regions may wonder that the Sicilians dare to live on the slopes of an active volcano, and especially that they return to their towns and fields before the recent streams of liquid rock have had time to cool. We see a close analogy to this tenacious determination and apparent disregard of danger, however, in the return of farmers to their homes beside the Mississippi River directly after the disastrous flood of 1927 subsided. In many parts of the world the struggle for existence is very real.

Numerous incidents reported from the vicinity of Etna in 1928 illustrate the nature and the effects of lava flows. The quotation from the *New York Times* for November 6 continues as follows:

> Though the material damage is incalculable no loss of life is expected, as all the threatened places have been evacuated. The roads in the endangered region are all jammed with motor trucks and motor cars transporting refugees and their effects. They are being housed in neighboring villages or in military camps erected at a safe distance. The entire population of the region, numbering many scores of thousands, is migrating with all its movable possessions.
>
> In other villages where the threat is somewhat more remote processions are being formed, headed by priests carrying images of patron saints and imploring mercy from Heaven.
>
> The lava completely cut off Mascali from the outside world today. Sweeping past Nunziata, which, being on a slight hillock, was spared, it first cut a railroad just above Mascali and

then rolled onward right across the northern end of Mascali, its nearest fringe only a few hundred yards from the heart of the town. It then cut the railroad and highway between Taormina and Catania.

The lava is now within about a mile of the sea. All communication northward from the zone south of Mascali is completely interrupted, telephone and telegraph wires having suffered the same fate as the railroads and roads.

Progress of the eruption, which consisted entirely of "quiet" flows, is explained in later despatches:

Rome, Nov. 8 (1928).—Where Mascali yesterday stood as a kind of bulwark against the lava advancing down Mount Etna's sides, there is to-day a molten waste. Only a few heaps of charred wreckage floating on a river of fuming, semi-liquid volcanic matter mark the spot where a town of 10,000 people flourished. That, and, higher up on the slope to the left, the cemetery, untouched, its marble tombstones showing white through the cinder-laden air as though mourning the death that has overtaken its town.

The belfry of Mascali's main church resisted long. It was the last thing to be submerged in the river of destruction. Just before it disappeared, it rocked with the lava's mighty thrust and its bells rang out mournfully, tolling without bellman a death knell for the town whose inhabitants they had so often gladdened on festive occasions.

Sweeping past Mascali the stream of lava reached the town's railroad station today and destroyed it completely. Gangs of men were at work just before the lava invaded the station. They removed the rails and made a breach in the high bank on which the track was laid at that point, in order to facilitate the flow of lava toward the sea. It is expected that the lava will reach the sea before morning. On its way it will certainly over-run the small village of Carrabba which, its fate being sealed, has been completely evacuated.

Anxiety now is centred on Giarre, the main town of the region, counting some 25,000 inhabitants. Two rivers of lava are advancing on Giarre, one from the northwest, and its fate hangs in the balance.

Thousands of soldiers and other workers were toiling like Trojans today in a heroic eleventh-hour effort to deflect the lava flow away from Giarre and toward the sea. Thousands of mines are being exploded round northern and western sides of the town, to create an artificial canal of enormous proportions as a kind of bed for the lava river leading it to the sea. Thousands of other workers are erecting huge earthen bulwarks outside Giarre to shield the town from the advancing lava.

Unfortunately there is no sign of the eruption abating in intensity. The lava, indeed, today appears to be more fluid and seems to have increased its rate of progress as though impatient to complete the work of ruin.

The eruptive crater continues to belch out lava without sign of decrease. Volcanologists declare that the eruptive phenomena will continue for a considerable time yet.

The first deaths from the eruption were reported today. Three peasants, hoping against hope that their house would be spared, refused to obey the orders of the authorities to evacuate it. Taken away by main force, they returned and re-entered their home at night. They realized some hours later, when it was already too late, that their house had been surrounded on all sides by the stealthily advancing lava.

Their cries for help were piteous, but nothing could be done to save them. A fiery gulf separated them from all human aid. Spectators looked on in impotent horror. Gradually the lava closed on them, first destroying their house and driving them into the open. Then slowly it swallowed them. Mercifully they were overcome by fumes before the lava reached their bodies and were thus spared the agony of death by burning.

The attitude of these three peasants who lost their lives is typical of that of all the inhabitants of this region. They are so attached to their homes that their houses appear to them more important than life itself. The police constantly must drag people away by main force to prevent them from practically committing suicide. As the lava advances many peasants retreat before it, step by step, loath to leave the places where they have spent all their lives. Many others are crazed or stupefied by sufferings both mental and physical.

Catania, Sicily, Nov. 8 (AP).—The devastating floods of molten lava making their way in three main streams down the slopes of Mount Etna were driving the terror-stricken population of towns at the foot of the volcano from their homes tonight.

Although heavy property damage has been caused by the lava overflowing fertile fields and several small villages, only three deaths have been reported. These were in the town of Mascali, where three men of the Pistorig family, a father, son and grandson, were overwhelmed in their home. The men had slipped to their doomed house overnight and this morning found them trapped. Their fate is being emphasized to all to prevent other casualties.

Late today the lava streams were making between ten and twelve yards an hour. This slowing up of the flow was attributed to variations in the nature of the ground which caused the three branches to deviate from their course.[1]

The three branches of lava traveled more than six miles in the past seventy-two hours, or about five times faster than the flow of 1923.

Professor Ponte has asked the Government for an airplane in order that he may fly over the volcanic region to study the situation more closely.

Rigorous measures are being taken to regulate traffic on the roads in the region.

Signor Giuratti, Minister of Public Works, who was one of D'Annunzio's chief lieutenants at Fiume, has been working night and day, exhorting the terror-stricken population to remain calm and mustering all aid for the assistance of the people. The populations of towns unaffected by the lava flow have been giving generous hospitality to the homeless.

---

[1] It was also due, of course, to the continued cooling and consequent congealing of the lava with increasing distance from the vent.—Ed. Note.

The branch that last night overran Mascali, however, was proceeding faster than the central current, and it was believed impossible to predict its future course.

Thousands of spectators who have been coming from all over Sicily and Calabria were obliged to park their cars far from the scene of the lava flow and to proceed afoot.

The spectacle of the relentlessly flowing lava seems to exercise a terrible fascination on men and beasts. A number of adventurous cats, lured into Mascali by the fiery sight, were destroyed.

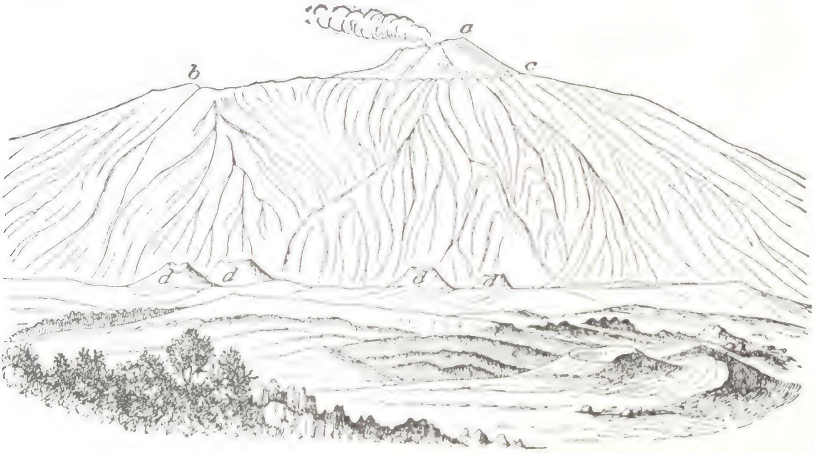
Birds also fell victims. Flocks of them hovered over the river of lava and many, often venturing too near, were caught by the fumes and fire to flutter down to the fiery bed below like dead leaves.

Pathetic incidents in Mascali were numerous. Last night two poor peasant women tearfully begged permission of the authorities to disinter the body of one of their relatives in order to bury it in a safer place. The advance of the lava, however, made it necessary that the request be refused, as time had become too precious.

A monument to the World War dead which was to have been unveiled this coming Sunday was hastily dedicated just before the lava reached it, Fascisti performing their rite of calling the names on the roll of dead while the crowd answered "present" after each.

Etna's eruption, which began last Friday, reached an acute stage to-day. Professor Ponte, Director of the Volcano Institute, estimated that the quantity of lava thus far thrown out equaled in one day that of the first two days of other eruptions of 1910, 1911, and 1923. As each of those lasted about eight days, it is feared that the present flow may continue at least several days longer.

This latest outbreak of Etna is somewhat exceptional in its destructiveness for the present generation; but lava flows have come from this volcano every few years since ancient times. Therefore the activity of this famous mountain is a commonplace to the people of Sicily. The successive eruptions have not come from one definite central vent, but have broken out unexpectedly on so many parts of the slope and even around the base of the mountain that a large area has a pock-marked appearance (Figs. 6 and 7). The central cone is a very high peak, and although some parts of the volcanic pile give forth hot vapors from the internal "fires," deep snow covers the summit during much of the year. Lyell (1860, pp. 411-412) records two unusual events connected with this icy covering of Etna:

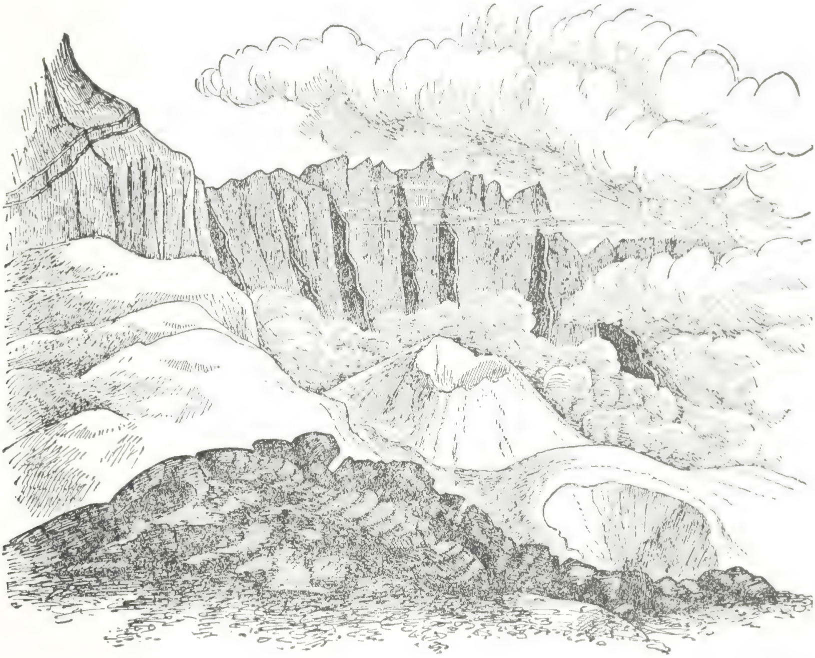


—From Sartorius von Waltershausen's *Atlas,* plate 2

FIG. 6.—TRUNCATED APPEARANCE OF THE SUMMIT OF ETNA ON THE NORTHWEST SIDE, AS SEEN FROM NEAR BRONTE.

a. Cone formed in early nineteenth century. *b, c.* Margin of highest platform. *d.* Minor cones.

Flood Produced by the Melting of Snow by Lava.—It is possible that some of the breccia or conglomerates may be referred to aqueous causes, as great floods occasionally sweep down the flanks of Etna, when eruptions take place in winter, and when the snows are melted by lava. It is true that running water in general exerts no power on Etna, the rain which falls being immediately imbibed by the porous lavas; so that, vast as is the extent of the mountain, it feeds only a few small rivulets, and these, even, are dry throughout the greater portion of the year. The enormous rounded boulders, therefore, of feldspar-porphyry and basalt, a line of which can be traced from the sea, from near Giardini, by Mascali, and Zafarana, to the "Val del Bove," would offer a perplexing problem to the geologist, if history had not preserved the memorials of a tremendous flood which happened in this district in the year 1755. It appears that two streams of lava flowed in that year, on the 2nd of March, from the highest crater; they were immediately precipitated upon an enormous mass of snow which then covered the whole mountain, and was extremely deep near the summit. The sudden melting of this frozen mass, by a fiery torrent three miles in length, produced a frightful inundation, which devastated the sides of the mountain for eight miles in



(After Lyell.)

FIG. 7.—VIEW FROM THE SUMMIT OF ETNA INTO THE VAL DEL BOVE.

length, and afterwards covered the lower flanks of Etna, where they were less steep, together with the plains near the sea, with great deposits of sand, scoriæ, and blocks of lava.

Many absurd stories circulated in Sicily respecting this event; such as that the water was boiling, and that it was vomited from the highest crater; that it was as salt as the sea, and full of marine shells; but these were mere inventions, to which Recupero, although he relates them as tales of the mountaineers, seems to have attached rather too much importance.

Glacier Covered by a Lava-stream.—A remarkable discovery was made on Etna in 1828 of a great mass of ice, preserved for many years, perhaps for centuries, from melting, by the singular accident of a current of red-hot lava having flowed over it. The following are the facts in attestation of a phenomenon which must at first sight appear of so paradoxical a character. The extraordinary heat experienced in the South of Europe, during the summer and autumn of 1828, caused the supplies of snow and ice which had been preserved in the spring of that year, for the use of Catania and the adjoining parts of Sicily and the island of Malta, to fail entirely. Great distress was consequently felt for want of a commodity regarded in those countries as one of the necessaries of life rather than an article of luxury, and the abundance of which contributes in some of the larger cities to the salubrity of the water and general health of the community. The magistrates of Catania applied to Signor M. Gemmellaro, in the hope that his local knowledge of Etna might enable him to point out some crevice or natural grotto in the mountain, where drift-snow was still preserved. Nor were they disappointed; for he had long suspected that a small mass of perennial ice at the foot of the highest cone was part of a large and continuous glacier covered by a lava-current. Having procured a large body of workmen, he quarried into this ice, and proved the superposition of the lava for several hundred yards, so as completely to satisfy himself that nothing but the subsequent flowing of the lava over the ice could account for the position of the glacier.

The apparent contradiction involved in the two accounts given above—melting of ice by one lava flow and preservation of a glacier by another—probably is explained by the comparative size of the two flows. A thin sheet of lava, spreading over a thick mass of compact ice, would of course cause considerable melting; but the lava in turn would be chilled quickly, and after solidification it would serve to insulate the remaining ice against atmospheric heat. Moreover a thick coating of dirt and other morainic débris on the surface of the glacier would serve to protect the ice from the effects of fluid lava until most of the heat became dissipated into the air.

Vesuvius, a neighbor of Etna in the Mediterranean volcanic region, is famous throughout the civilized world. The classic eruption of this mountain during the first century A.D. and its recurrent activity in modern times have made it perhaps the best known of all volcanoes. Lyell (1860, pp. 363-374) has outlined for us the complete history of Vesuvius from ancient times. After a brief account of known volcanic activity about the Bay of Naples before the time of Christ, he writes:

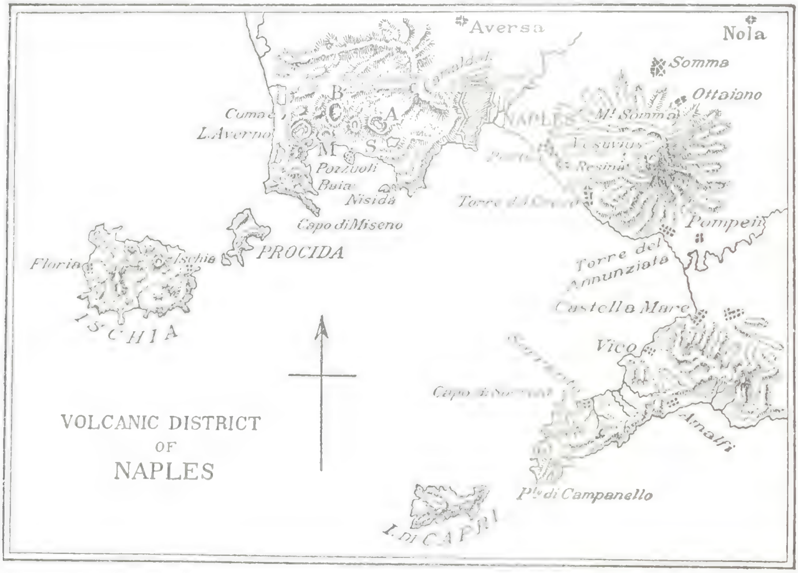
Ancient History of Vesuvius.—Such, then, were the points where the subterranean fires obtained vent, from the earliest period to which tradition reaches back, down to the first century of the Christian era; but we then arrive at a crisis in the volcanic action of this district—one of the more interesting events witnessed by man during the brief period throughout which he has observed the physical changes on the earth's surface. From the first colonization of Southern Italy by the Greeks, Vesuvius afforded no other indications of its volcanic character than such as the naturalist might infer, from the analogy of its structure to other volcanoes. These were recognized by Strabo, but Pliny did not include the mountain in his list of active vents. The ancient cone was of a very regular form, terminating not as at present in two peaks, but with a summit which presented, when seen from a distance, the even outline of an abruptly truncated cone. On the summit, as we learn from Plutarch, there was a crater with steep cliffs, and having its interior overgrown with wild vines, and with a sterile plain at the bottom. On the exterior, the flanks of the mountain were clothed with fertile fields richly cultivated, and at its base were the populous cities of Herculaneum and Pompeii. But the scene of repose was at length doomed to cease, and the volcanic fire was recalled to the main channel, which at some former unknown period had given passage to repeated streams of melted lava, sand, and scoriæ.

Renewal of Its Eruptions.—The first symptom of the revival of the energies of this volcano was the occurrence of an earthquake in the year 63 after Christ, which did considerable injury to the cities in its vicinity. From that time to the year 79 slight shocks were frequent; and in the month of August of that year they became more numerous and violent, till they ended at length in an eruption. The elder Pliny, who commanded the Roman fleet, was then stationed at Misenum; and in his anxiety to obtain a near view of the phenomena, he lost his life, being suffocated by sulphurous vapors. His nephew, the younger Pliny, remained at Misenum, and has given us, in his letters, a lively description of the awful scene. A dense column of vapor was first seen rising vertically from Vesuvius, and then spreading itself out laterally, so that its upper portion resembled the head, and its lower the trunk of the pine, which characterizes the Italian landscape. This black cloud was pierced occasionally by flashes of fire, as vivid as lightning, succeeded by darkness more profound than night. Ashes fell even upon the ships at Misenum, and caused a shoal in one part of the sea—the ground rocked, and the sea receded from the shores, so that many marine animals were seen on the dry sand. The appearances above described agree perfectly with those witnessed in more recent eruptions, especially those of Monte Nuovo, in 1538, and of Vesuvius in 1822.

The younger Pliny, although giving a circumstantial detail of so many physical facts, and describing the eruption and earthquake, and the shower of ashes which fell at Stabiæ, makes no allusion to the sudden overwhelming of two large and populous cities, Herculaneum and Pompeii. In explanation of this omission, it has been suggested that his chief object was simply to give Tacitus a full account of the particulars of his uncle's death. It is worthy, however, of remark, that had the buried cities never been discovered, the accounts transmitted to us of their tragical end might well have been discredited by the majority, so vague and general are the narratives, or so long and subsequent to the event. Tacitus, the friend and contemporary of Pliny, when adverting in general terms to the convulsions, says merely that "cities were consumed or buried."

Suetonius, although he alludes to the eruption incidentally, is silent as to the cities. They are mentioned by Martial, in an epigram, as immersed in cinders; but the first historian who alludes to them by name is Dion Cassius, who flourished about a century and a half after Pliny. He appears to have derived his information from the traditions of the inhabitants, and to have recorded, without discrimination, all the facts and fables which he could collect. He tells us, "that during the eruption a multitude of men of superhuman stature, resembling giants, appeared, sometimes on the mountains, and sometimes in the environs—that stones and smoke were thrown out, the sun was hidden, and then the giants seemed to rise again, while the sounds of trumpets were heard, etc., etc.; and finally," he relates, "two entire cities, Herculaneum and Pompeii, were buried under showers of ashes, while all the people were sitting in the theatre." That many of these circumstances were invented, would have been obvious, even without the aid of Pliny's letters; and the examination of Herculaneum and Pompeii enables us to prove, that none of the people were destroyed in the theatres, and indeed that there were very few of the inhabitants who did not escape from both cities. Yet some lives were lost, and there was ample foundation for the tale in its most essential particulars.

It does not appear that in the year 79 any lava flowed from Vesuvius; the ejected substances, perhaps, consisted entirely of lapilli, sand, and fragments of older lava, as when Monte Nuovo was thrown up in 1538. The first era at which we have authentic accounts of the flowing of a stream of lava, is the year 1036, which is the seventh eruption from the revival of the fires of the volcano. A few years afterwards, in 1049, another eruption is mentioned, and another in 1138 (or 1139), after which a great pause ensued of 168 years. During this long interval of repose, two minor vents opened at distant points. First, it is on tradition that an eruption took place from the Solfatara, in the year 1198, during the reign of Frederick II, Emperor of Germany; and although no circumstantial detail of the event has reached us from those dark ages, we may receive the fact without hesitation. Nothing more, however, can be attributed to this eruption, as Mr. Scrope observes, than the discharge of a light and scoriform trachytic

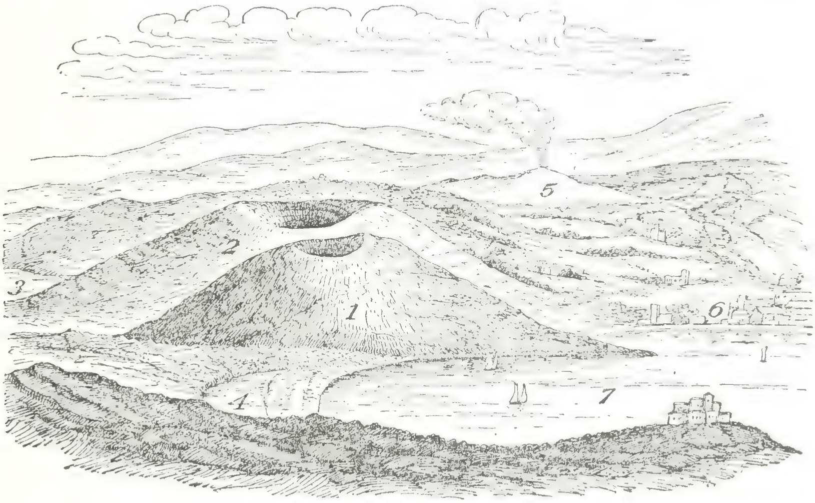


(After Lyell.)

FIG. 8.—A. ASTRONI. B. MONTE BARBARO. M. MONTE NUOVO. S. THE SOLFATARA.

lava, of recent aspect, resting upon the strata of loose tuff which covers the principal mass of trachyte.

History of Vesuvius After 1138.—The next eruption occurred in 1306; between which era and 1631 there was only one other (in 1500), and that a slight one. It has been remarked, that throughout this period Etna was in a state of such unusual activity, as to lend countenance to the idea that the great Sicilian volcano may sometimes serve as a channel to discharge the elastic fluids and lava that would otherwise rise to the vents in Campania.



(After Lyell.)

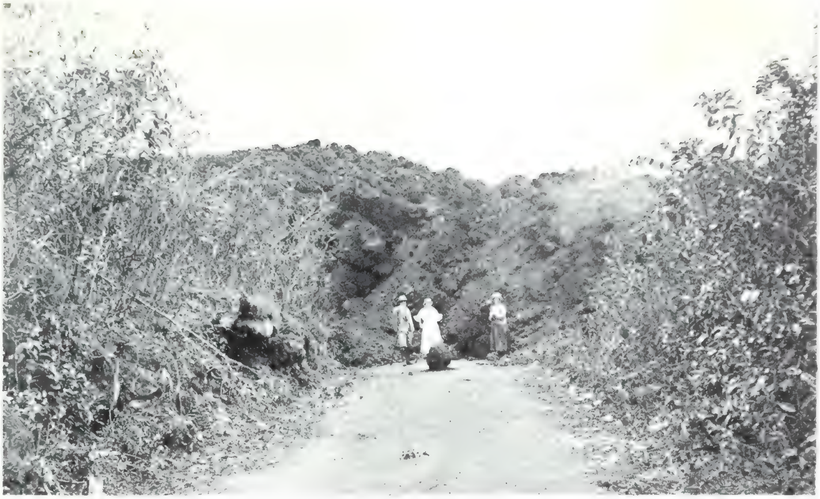
FIG. 9.—THE PHLEGRÆAN FIELDS.

1. Monte Nuovo.
2. Monte Barbaro.
3. Lake Avernus.
4. Lucrine Lake.
5. The Solfatara.
6. Puzzuoli.
7. Bay of Baiæ.

Formation of Monte Nuovo, 1538.—The great pause was also marked by a memorable event in the Phlegræan Fields—the sudden formation of a new mountain in 1538, of which we have received authentic accounts from contemporary writers.

Sir William Hamilton has given us two original letters describing this eruption. The first, by Falconi, dated 1538, contains the following passages: "It is now two years since there have been frequent earthquakes at Puzzuoli, Naples, and the neighboring parts. On the day and in the night before the eruption (of Monte Nuovo), above twenty shocks, great and small, were felt. The eruption began on the 29th of September, 1538. It was on a Sunday, about one o'clock in the night, when flames of fire were seen between the hot baths and Tripergola. In a short time the fire increased to such a degree, that it burst open the earth in this place, and threw up so great a quantity of ashes and pumice-stones, mixed with water, as covered the whole country. The next morning (after the formation of Monte Nuovo) the poor inhabitants of Puzzuoli quitted their habitations in terror, covered with the muddy and black shower which continued the whole day in that country—flying from death, but with death painted in their countenances. Some with their children in their arms, some with sacks full of their goods; others leading an ass, loaded with their frightened family, towards Naples; others carrying quantities of birds of various sorts, which had fallen dead at the beginning of the eruption; others, again, with fish which they had found, and which were to be met with in plenty on the shore, the sea having left them dry for a considerable time. I accompanied Signor Moramaldo to behold the wonderful effects of the eruption. The sea had retired on the side of Baiæ, abandoning a considerable tract, and the shore appeared almost entirely dry, from the quantity of ashes and broken pumice-stones thrown up by the eruption. I saw two springs in the newly discovered ruins; one before the house that was the queen's, of hot and salt water," etc.

So far Falconi: the other account is by Pietro Giacomo di Toledo, which begins thus: "It is now two years since this province of Campagna has been afflicted with earthquakes, the country about Puzzuoli much more so than any other parts; but the 27th and the 28th of the month of September last, the earthquakes did not cease day or night in the town of Puzzuoli: that plain which lies between Lake Avernus, the Monte Barbaro, and the sea was *raised a little,* and many cracks were



Hawaiian Volcano Observatory

A. A LAVA BARRIER

The front of this flow from Mauna Loa in 1926 stopped squarely across a road.

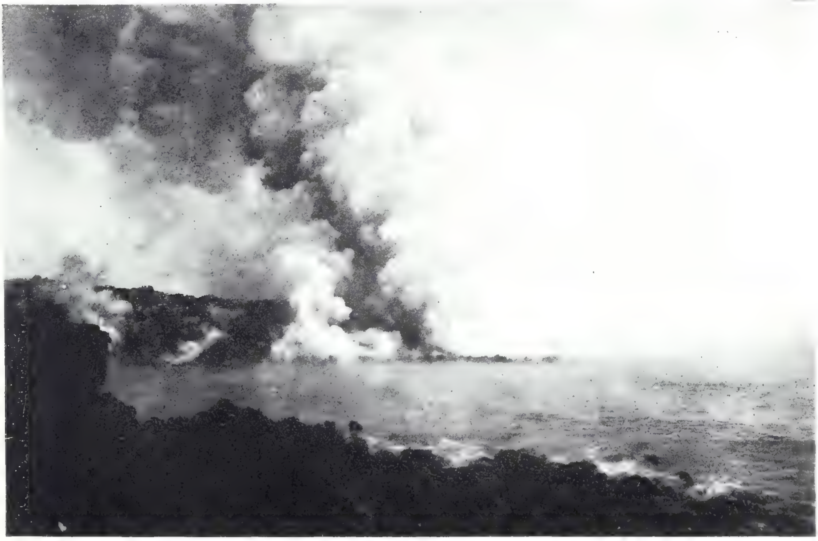


Photo M. Fuyura

B. PUTTING OUT VOLCANIC FIRES

Lava flow entering the sea at Hoopuloa during the eruption of Mauna Loa in 1926.

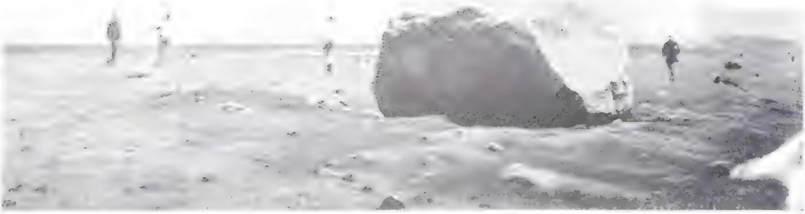


Photo Tai Sing Loo

A. A HUGE PROJECTILE

An eight-ton boulder thrown from the pit of Kilauea, May 18, 1924. It landed half a mile from the crater rim.

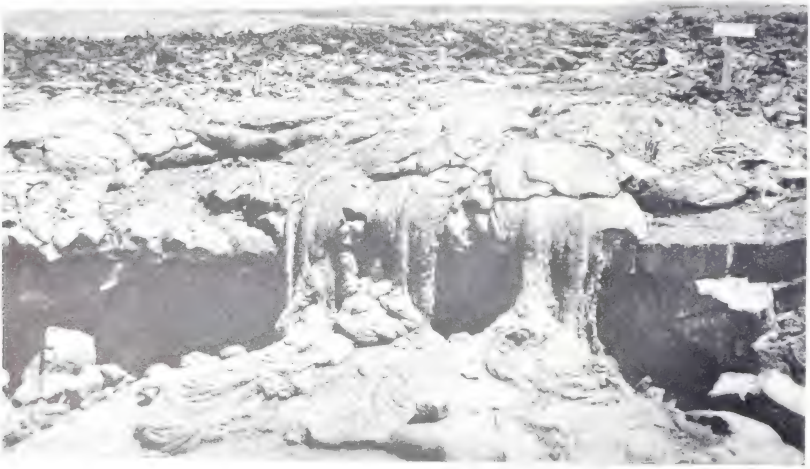


Photo Kanemori

B. PAHOEHOE

A solidified lava cascade, Hawaii. The basalt is of the smooth, ropy variety.

made in it, from some of which issued water; at the same time the sea, immediately joining the plain, *dried up about two hundred paces,* so that the fish were left on the sand a prey to the inhabitants of Puzzuoli. At last, on the 29th of the same month, about two o'clock in the night, the earth opened near the lake, and discovered a horrid mouth, from which were vomited furiously smoke, fire, stones, and mud, composed of ashes, making at the time of its opening a noise like the loudest thunder. The stones which followed were by the flames converted to pumice, and some of these were *larger than an ox.* The stones went about as high as a cross-bow can carry, and then fell down, sometimes on the edge, and sometimes into the mouth itself. The mud was of the color of ashes, and at first very liquid, then by degrees less so, and in such quantities, that in less than twelve hours, with the help of the above-mentioned stones, a mountain was raised 1,000 paces in height. Not only Puzzuoli and the neighboring country was full of this mud, but the city of Naples also; so that many of its palaces were defaced by it. Now this eruption lasted two nights and two days without intermission, though, it is true, not always with the same force; the third day the eruption ceased, and I went up with many people to the top of the new hill, and saw down into its mouth, which was a round cavity about a quarter of a mile in circumference, in the middle of which, the stones which had fallen were boiling up, just as a caldron of water boils on the fire. The fourth day it began to throw up again, and the seventh much more, but still with less violence than the first night. At this time many persons who were on the hill were knocked down by the stones and killed, or smothered with the smoke. In the day the smoke still continues, and you often see fire in the midst of it in the night-time."

It will be seen that both these accounts, written immediately after the birth of Monte Nuovo, agree in stating that the sea retired; and one mentions that its bottom was upraised; but they attribute the origin of the new hill exclusively to the jets of mud, showers of scoriæ, and large fragments of rock, cast out from a central orifice, for several days and nights. Baron Von Buch, however, in his excellent work on the Canary Islands, and volcanic phenomena in general, has declared his opinion that the cone and crater of Monte Nuovo were formed, not in the manner above described, but by the upheaval of solid beds of white tuff, which were previously horizontal, but which were pushed up in 1538, so as to dip away in all directions from the centre, with the same inclination as the sloping surface of the cone itself. "It is an error," he says, "to imagine that this hill was formed by eruption, or by the ejection of pumice, scoriæ, and other incoherent matter; for the solid beds of upraised tuff are visible all round in the crater, and it is merely the superficial covering of the cone which is made up of ejected scoriæ."

In confirmation of this view, M. Dufrenoy has cited a passage from the works of Porzio, a celebrated physician of that period, to prove that in 1538 the ground where Monte Nuovo stands was pushed up in the form of a great bubble or blister, which on bursting, gave origin to the present deep crater. Porzio says, "that after two days and nights of violent earthquakes, the sea retired for nearly 200 yards; so that the inhabitants could collect great numbers of fish on this part of the shore, and see some springs of fresh water which rose up there. At length, on the third day of the calends of October (September 29), they saw a large tract of ground intervening between the foot of Monte Barbaro, and part of the sea, near the Lake Avernus, rise, and suddenly assume the form of an incipient hill; and at two o'clock at night, this heap of earth, opening as it were its mouth, vomited, with a loud noise, flames, pumice-stones, and ashes."

So late as the year 1846 a fourth manuscript (written immediately after the eruption) was discovered and published in Germany. It was written in 1538 by Francesco del Nero, who mentions the drying up of the bed of the sea near Puzzuoli, which enabled the inhabitants of the town to carry off loads of fish. About eight o'clock in the morning of the 29th September, the earth sunk down about 14 feet in that place where the volcanic orifice now appears, and there issued forth a small stream of water, at first cold, and afterwards tepid. At noon, on the same day, the earth began to swell up in the same spot where it had sunk down 14 feet, so as to form a hill. About this time fire issued forth, and gave rise to the great gulf, "with such a force, noise and shining light, that I, who was standing in my garden, was seized with terror. Forty minutes afterwards, although unwell, I got upon a neighboring height, from which I saw all that took place, and by my troth it was a splendid fire, that threw up for a long time much earth and many stones, which fell back again all round the gulf, in a semicircle of from one to three bowshots in diameter, and, filling up part of the sea, formed a hill nearly of the height of Monte Morello. Masses of earth and stones, as large as an ox, were shot up from the fiery gulf into the air, to a height which I estimate at a mile and a half. When they descended, some were dry, others in a soft muddy state." He concludes by alluding again to the sinking of the ground, and the elevation of it which followed, and says that to him it was inconceivable how such a mass of stones and ashes could have been poured forth from the gulf. He also refers to the account which Porzio was to draw up for the Viceroy.

On comparing these four accounts, recorded by eye-witnesses, there appears to be no real discrepancy between them. It seems clear that the ground first sunk down 14 feet on the site of the future volcano, and after having subsided it was again propelled upwards by the lava mingled with steam and gases, which were about to burst forth. Jets of red-hot lava, fragments of fractured rock, and occasionally mud composed of a mixture of pumice, tuff, and sea-water, were hurled into the air. Some of the blocks of stone were very large, leading us to infer that the ground which sank and rose again was much shattered and torn to pieces by the elastic vapors. The whole hill was not formed at once, but by an intermittent action extending over a week or more. It seems that the chasm opened between Tripergola and the baths in its suburbs, and that the ejected materials fell and buried that small town. A considerable part, however, of the hill was formed in less than twenty-four hours, and in the same manner as on a smaller scale the mud cones of the air volcanoes are produced, with a cavity in the middle. There is no difficulty in conceiving that the pumiceous mud, if so thrown out, may have set into a kind of stone on drying, just as some cements, composed of volcanic ashes, are known to consolidate with facility.

Modern Eruptions of Vesuvius.—For nearly a century after the birth of Monte Nuovo, Vesuvius continued in a state of tranquillity. There had been no violent eruption for 492 years; and it appears that the crater was then exactly in the condition of the present extinct volcano of Astroni, near Naples. Bracini, who visited Vesuvius not long before the eruption of 1631, gives the following interesting description of the interior: "The crater was five miles in circumference, and about a thousand paces deep: its sides were covered with brushwood, and at the bottom there was a plain on which cattle grazed. In the woody parts wild boars frequently harbored. In one part of the plain, covered with ashes, were three small pools, one filled with hot and bitter water, another salter than the sea, and a third hot but tasteless." But at length these forests and grassy plains were consumed, being suddenly blown into the air, and their ashes scattered to the winds. In December, 1631, seven streams of lava poured at once from the crater, and overflowed several villages, on the flanks and at the foot of the mountains. Resina, partly built over the ancient site of Herculaneum, was consumed by the fiery torrent. Great floods of mud were as destructive as the lava itself,—no uncommon occurrence during these catastrophes; for such is the violence of rains produced by the evolution of aqueous vapor, that torrents of water descend the cone, and becoming charged with impalpable volcanic dust, and rolling along loose ashes, acquire sufficient consistency to deserve their ordinary appellation of "aqueous lavas."

> A brief period of repose ensued, which lasted only until the year 1666, from which time to the present there has been a constant series of eruptions, with rarely an interval of rest exceeding ten years. During these three centuries, no irregular volcanic agency has convulsed other points in this district. Brieslak remarked that such irregular convulsions had occurred in the Bay of Naples in every second century; as, for example, the eruption of the Solfatara, in the twelfth; of the lava of Arso, in Ischia, in the fourteenth; and of Monte Nuovo in the sixteenth; but the eighteenth has formed an exception to this rule, and this seems accounted for by the unprecedented number of eruptions of Vesuvius during that period; whereas, when the new vents opened, there had always been, as we have seen, a long intermittence of activity in the principal volcano.

Many notable eruptions of Vesuvius have occurred since Lyell's time. The "constant series" of which he speaks, starting in 1666, is still in progress. The continuous "smoking" of the mountain is considered a normal condition, and every few years there is sufficient activity to cause apprehension. Occasionally, as in 1906, there are violent explosions and destructive floods of lava.

Pompeii and Herculaneum are inevitably called to mind in connection with Vesuvius. Lyell (1860, pp. 389-393) gives the following discussion of these two buried cities:

> *Herculaneum.*—It was remarked that no lava has flowed over the site of Pompeii, since that city was built, but with Herculaneum the case is different. Although the substance which fills the interior of the houses and the vaults must have been introduced in a state of mud, like that found in similar situations in Pompeii; yet the superincumbent mass differs wholly in composition and thickness. Herculaneum was situated several miles nearer to the volcano, and has, therefore, been always more exposed to be covered, not only by showers of ashes, but by alluviums and streams of lava. Accordingly, masses of both have been accumulated on each other above the city, to a depth of nowhere less than 70, and in many places of 112 feet.

The tuff which envelops the buildings consists of comminuted volcanic ashes, mixed with pumice. A mask imbedded in this matrix has left a cast, the sharpness of which was compared by Hamilton to those in plaster of Paris; nor was the mask in the least degree scorched, as if it had been imbedded in heated matter. This tuff is porous; and, when first excavated, is soft and easily worked, but acquires a considerable degree of induration on exposure to the air. Above this lowest stratum is placed, according to Hamilton, "the matter of six eruptions," each separated from the other by layers of good soil. In these soils Lippi states that he collected a considerable number of land shells—an observation which is no doubt correct; for many snails burrow in soft soils, and some Italian species descend, when they hibernate, to the depth of five feet and more from the surface. Della Terre also informs us that there is in one part of this superimposed mass a bed of true siliceous lava (*lava di pietra dura*); and, as no such current is believed to have flowed till near one thousand years after the destruction of Herculaneum, we must conclude, that the origin of a large part of the covering of Herculaneum was long subsequent to the first inhumation of the place. That city, as well as Pompeii, was a seaport. Herculaneum is still very near the shore, but a tract of land, a mile in length, intervenes between the borders of the Bay of Naples and Pompeii. In both cases the gain of land is due to the filling up of the bed of the sea with volcanic matter, and not to elevation, for there has been no change in the relative level of land and sea. Pompeii stood on a slight eminence composed of the lavas of the ancient Vesuvius, and flights of steps led down to the water's edge. The lowermost of these steps are said to be still on an exact level with the sea.

Condition and Contents of the Buried Cities.—After these observations on the nature of the strata enveloping and surrounding the cities, we may proceed to consider their internal condition and contents, so far at least as they offer facts of geological interest. Notwithstanding the much greater depth at which Herculaneum was buried, it was discovered before Pompeii, by the accidental circumstance of a well being sunk, in 1713, which came right down upon the theatre, where the statues of Hercules and Cleopatra were soon found. Whether this city or Pompeii, both of them founded by Greek colonies, was the more considerable, is not yet determined; but both are mentioned by ancient authors as among the seven most flourishing cities in Campania. The walls of Pompeii were three miles in circumference; but we have, as yet, no certain knowledge of the dimensions of Herculaneum. In the latter place the theatre alone is open for inspection; the Forum, Temple of Jupiter, and other buildings, having been filled up with rubbish as the workmen proceeded, owing to the difficulty of removing it from so great a depth below ground. Even the theatre is only seen by torch light, and the most interesting information, perhaps, which the geologist obtains there, is the continual formation of stalactite in the galleries cut through the tuff; for there is a constant percolation of water charged with carbonate of lime mixed with a small portion of magnesia. Such mineral waters must, in the course of time, create great changes in many rocks; especially in lavas, the pores of which they may fill with calcareous spar, so as to convert them into amygdaloids. Some geologists, therefore, are unreasonable when they expect that volcanic rocks of remote eras should accord precisely with those of modern date; since it is obvious that many of those produced in our own time will not long retain the same aspect and internal composition.

Both at Herculaneum and Pompeii, temples have been found with inscriptions commemorating the rebuilding of the edifices after they had been thrown down by an earthquake. This earthquake happened in the reign of Nero, sixteen years before the cities were overwhelmed. In Pompeii, one-fourth of which is now laid open to the day, both the public and private buildings bear testimony to the catastrophe. The walls are rent, and in many places traversed by fissures still open. Columns are lying on the ground only half hewn from huge blocks of travertine, and the temple for which they were designed is seen half repaired. In some few places the pavement has sunk in, but in general it was undisturbed, consisting of large irregular flags of lava joined nearly together, in which the carriage wheels have often worn ruts an inch and a half deep. In the wider streets, the ruts are numerous and irregular; in the narrower, there are only two, one on each side, which are very conspicuous. It is impossible not to look with some interest even on these ruts, which were worn by chariot wheels more than seventeen centuries ago; and, independently of their antiquity, it is remarkable to see such deep incisions so continuous in a stone of great hardness.

Small Number of Skeletons.—A very small number of skeletons have been discovered in either city; and it is clear that most of the inhabitants not only found time to escape, but also to carry with them the principal part of their valuable effects. In the Barracks at Pompeii were the skeletons of two soldiers chained to the stocks, and in the vaults of a country-house in the suburbs were the skeletons of seventeen persons, who appear to have fled there to escape from the shower of ashes. They were found inclosed in an indurated tuff, and in this matrix was preserved a perfect cast of a woman, perhaps the mistress of the house, with an infant in her arms. Although her form was imprinted on the rock, nothing but the bones remained. To these a chain of gold was suspended, and on the fingers of the skeletons were rings with jewels. Against the sides of the same vault was ranged a long line of earthen amphoræ.

The writings scribbled by the soldiers on the walls of their barracks, and the names of the owners of each house written over the doors, are still perfectly legible. The colors of fresco paintings on the stuccoed walls in the interior of buildings are almost as vivid as if they were just finished. There are public fountains decorated with shells laid out in patterns in the same fashion as those now seen in the town of Naples; and in the room of a painter, who was perhaps a naturalist, a large collection of shells was found, comprising a great variety of Mediterranean species, in as good a state of preservation as if they had remained for the same number of years in a museum. A comparison of these remains with those found so generally in a fossil state would not assist us in obtaining the least insight into the time required to produce a certain degree of decomposition or mineralization; for, although under favorable circumstances much greater alteration might doubtless have been brought about in a shorter period, yet the example before us shows that an inhumation of seventeen centuries may sometimes effect nothing towards the reduction of shells to the state in which fossils are usually found.

The wooden beams in the houses at Herculaneum are black on the exterior, but, when cleft open, they appear to be almost in the state of ordinary wood, and the progress made by the whole mass towards the state of lignite is scarcely appreciable. Some animal and vegetable substances of more perishable kinds have of course suffered much change and decay, yet the state of preservation of these is truly remarkable. Fishing-nets are very abundant in both cities, often quite entire; and their number at Pompeii is the more interesting from the sea being now, as we stated, a mile distant. Linen has been found at Herculaneum, with the texture well defined; and in a fruiterer's shop in that city were discovered vessels full of almonds, chestnuts, walnuts, and fruit of the "carubiere," all distinctly recognizable from their shape. A loaf, also, still retaining its form, was found in a baker's shop, with his name stamped upon it. On the counter of an apothecary was a box of pills converted into a fine earthy substance; and by the side of it a small cylindrical roll evidently prepared to be cut into pills. By the side of these was a jar containing medicinal herbs. In 1827, moist olives were found in a square glass-case, and "caviare," or roe of a fish, in a state of wonderful preservation. An examination of these curious condiments has been published by Covelli of Naples, and they are preserved hermetically sealed in the museum there.

Papyri.—There is a marked difference in the condition and appearance of the animal and vegetable substances found at Pompeii and Herculaneum; those of Pompeii being penetrated by a gray pulverulent tuff, those in Herculaneum seeming to have been first enveloped by a paste which consolidated round them, and then allowed them to become slowly carbonized. Some of the rolls of papyrus at Pompeii still retain their form; but the writing, and indeed almost all the vegetable matter, appear to have vanished, and to have been replaced by volcanic tuff somewhat pulverulent. At Herculaneum the earthy matter has scarcely ever penetrated; and the vegetable substance of the papyrus has become a thin friable black matter, almost resembling in appearance the tinder which remains when stiff paper has been burnt, in which the letters may still be sometimes traced. The small bundles of papyri, composed of five or six rolls tied up together, had sometimes lain horizontally, and were pressed in that direction, but sometimes they had been placed in a vertical position. Small tickets were attached to each bundle, on which the title of the work was inscribed. In one case only have the sheets been found with writing on both sides of the pages. So numerous are the obliterations and corrections, that many must have been original manuscripts. The variety of handwritings is quite extraordinary: nearly all are written in Greek, but there are a few in Latin. They were almost all found in a suburban villa in the library of one private individual; and the titles of four hundred of those least injured, which have been read, are found to be unimportant works, but all entirely new, chiefly relating to music, rhetoric, and cookery. There are two volumes of Epicurus "On Nature," and the others are mostly by writers of the same school, only one fragment having been discovered by an opponent of the Epicurean system, Chrysippus.[1]

---

[1] In one of the manuscripts which was in the hands of the interpreters when I visited the museum in 1828, the author indulges in the speculation that all the Homeric personages were allegorical—that Agamemnon was the ether, Achilles the sun, Helen the earth, Paris the air, Hector the moon, etc.

The cone of Vesuvius, built up by a combination of débris from explosive eruptions and lavas from relatively quiet effusions, is a commanding pile that dominates the Bay of Naples. Any one who has accepted this symmetrical cone as the type volcano may be disappointed at first sight of the Hawaiian volcanoes, which are composed chiefly of basaltic lava. This reaction is suggested in the following letter (Gilman, 1899, pp. 124-125) written by James D. Dana in 1840, while he was a young man and a member of the Wilkes expedition in the Pacific:

> I was astonished with the tameness of the lofty Mauna Loa. I have never seen a mountain one-third its height so utterly destitute of all sublimity or grandeur as this mountain appeared to us, walking along at its foot. It is an evenly rounded elevation, without one valley or gorge, one peak or ridge, to diversify its surface. I can compare its shape to nothing better than a saucer turned upside down. There are some gullies and slightly elevated ridges, which the traveller occasionally meets, but they do not appear in the distant prospect. Its slopes are so even and gradual that the top is much farther off than appears to the observer, and this accounts for his disappointment. The volcano, which you know is on the flanks of this mountain, about 4,000 feet up, was in considerable action while we were there.[1] The deep gulf which forms the crater, is surrounded by precipitous walls on all sides. About a thousand feet down there is a flat terrace running around, called the black ledge, which is in some parts half a mile wide. From this terrace there is a further descent of three hundred feet by equally perpendicular walls of rock, at the bottom of which is the scene of action. In three pools, one of them a thousand feet in its larger diameter, the lava was briskly boiling,—not the sluggish fluid we generally conceive it to be, but in appearance nearly as fluid as water. I descended to the lowest depths, wandered over the heated lavas, through the hot vapors and sulphurous gases, and reached one of the boiling

---

[1] The reference is to Kilauea, which is on the flank of Mauna Loa.—Ed. Note.

> pools. The surface was in constant motion, throwing up small jets six or eight feet, which fell around the sides of the pool. There was no explosion, and only a dull grumbling sound. All was as quiet as the boiling water in a pot over a kitchen fire. Occasional detonations, however, warned us of the dormant force below. At night the scene was sublime beyond description. The deep red glow of the boiling lake, reflected by the walls of the crater, and lighting up the canopy of clouds which overhung this fiery gulf, made a most sublime and awful spectacle at night, when all else around was black darkness. There was an eruption about six months since, and a large stream flowed down to the sea. The first appearance of the lava stream took place about eight miles from the crater. The stream near the sea is yet hot in many parts, and numerous steam holes are scattered over the surface.

Like Hawaii Iceland is built chiefly of basaltic lavas, and the building is still in progress. The famous fissure eruption of nearly a hundred and fifty years ago is known as the greatest lava flood in historic time. Lyell (1860, pp. 425-427) gives the following account of this eruption:

> *Great Eruption of Skaptar Jokul.*—Earthquakes which had long been felt in Iceland became violent on the 11th of June, 1783, when Skaptar Jokul, distant nearly 200 miles from Nyöe, threw out a torrent of lava which flowed down into the river Skaptâ, and completely dried it up. The channel of the river was between high rocks, in many places from four hundred to six hundred feet in depth, and near two hundred in breadth. Not only did the lava fill up this great defile to the brink, but it overflowed the adjacent fields to a considerable extent. The burning flood on issuing from the confined rocky gorge, was then arrested for some time by a deep lake, which formerly existed in the course of the river, between Skaptardal and Aa, which it entirely filled. The current then advanced again, and reaching some ancient lava full of subterraneous

caverns, penetrated and melted down part of it; and in some places, where the steam could not gain vent, it blew up the rock, throwing fragments to the height of more than 150 feet. On the 18th of June another ejection of liquid lava rushed from the volcano, which flowed down with amazing velocity over the surface of the first stream. By the damming up of the mouths of some of the tributaries of the Skaptâ, many villages were completely overflowed with water, and thus great destruction of property was caused. The lava, after flowing for several days, was precipitated down a tremendous cataract called Stapafoss, where it filled a profound abyss, which that great waterfall had been hollowing out for ages, and after this, the fiery current again continued its course.

On the third of August, fresh floods of lava still pouring from the volcano, a new branch was sent off in a different direction; for the channel of the Skaptâ was now so entirely choked up, and every opening to the west and north so obstructed, that the melted matter was forced to take a new course, so that it ran in a southeast direction, and discharged itself into the bed of the river Hverfisfliot, where a scene of destruction scarcely inferior to the former was occasioned. These Icelandic lavas (like the ancient streams which are met with in Auvergne, and other provinces of Central France), are stated by Stephenson to have accumulated to a prodigious depth in narrow rocky gorges; but when they came to wide alluvial plains, they spread themselves out into broad burning lakes, sometimes from twelve to fifteen miles wide, and one hundred feet deep. When the "fiery lake" which filled up the lower portion of the valley of the Skaptâ had been augmented by new supplies, the lava flowed up the course of the river to the foot of the hills from whence the Skaptâ takes its rise. This affords a parallel case to one which can be shown to have happened at a remote era in the volcanic region of the Vivarais in France, where lava issued from the cone of Thueyts, and while one branch ran down, another more powerful stream flowed up the channel of the river Ardêche.

The sides of the valley of the Skaptâ present superb ranges of basaltic columns of older lavas, resembling those which are laid open in the valleys descending from Mont Dor, in Auvergne, where more modern lava-currents, on a scale very inferior in magnitude to those of Iceland, have also usurped the beds of the existing rivers. The eruption of Skaptar Jokul did not entirely cease till the end of two years; and when Mr. Paulson visited the tract eleven years afterwards, in 1794, he found columns of smoke still rising from parts of the lava, and several rents filled with hot water.

Although the population of Iceland was very much scattered, and did not exceed fifty thousand, no less than twenty villages were destroyed, beside those inundated by water; and more than nine thousand human beings perished, together with an immense number of cattle, partly by the depredations of the lava, partly by the noxious vapors which impregnated the air, and, in part, by the famine caused by showers of ashes throughout the island, and the desertion of the coast by the fish.

Immense Volume of the Lava.—But the extraordinary volume of melted matter produced in this eruption deserves the particular attention of the geologist. Of the two branches, which flowed in nearly opposite directions, the greatest was fifty, and the lesser forty miles in length. The extreme breadth which the Skaptâ branch attained in the low countries was from twelve to fifteen miles, that of the other about seven. The ordinary height of both currents was one hundred feet, but in narrow defiles it sometimes amounted to six hundred. Professor Bischoff has calculated that the mass of lava brought up from the subterranean regions by this single eruption surpassed in magnitude the bulk of Mont Blanc.

The effect of volcanic outbursts in the midst of glacial ice, illustrated on a small scale in the records of Etna, are far more pronounced in Iceland where glaciers are large and the heat liberated by the larger eruptions is enormous. Without question the results of unusual floods generated in this way are of some importance in geology, since volcanoes and glaciers probably have been associated in many geologic periods. The following paragraphs (Jaggar, 1928) give some idea of the disastrous consequences of this association:

> The effect of volcanic heating on glaciers in Iceland is of great interest in comparison with what may happen on the glacier-covered volcanoes of Alaska. This melting was supposed to happen on the snow-covered Lassen Volcano of California. It may even have happened some thousands of years ago in Hawaii, when glaciers lay on top of Mauna Loa and Mauna Kea. This may account for some Hawaiian tuff deposits. The heat of the eruption melts the snow and ice masses, and the warmed water melts out gorges in the glaciers, increases in volume, and mixes with volcanic and glacial débris so as to make colossal torrents carrying icebergs out over the lowlands. These glacial floods are common in Iceland, where they are known as "Jokulhlaup" or glacier rushes. . . .
>
> At Katla, Iceland, in 1918, several openings trending SW-NE, about 1,000 meters above sea level, went into action along this crater which had become buried under ice since 1823, when it was last active. At 2 o'clock in the afternoon of October 12, 1918, after a swarm of weak earthquakes, steam clouds shot up, and for three nights thereafter these were full of electric fireworks. Human electrical operations, such as telegraph and telephone, were interrupted. There was much rumbling, and heavy ash-fall occurred and shrouded much of the land in darkness. This continued off and on for 20 days, with maxima about the 10th and 21st day. In a radius of one kilometer 698,220,000 cubic meters of ash fell.
>
> The warm water streams from the melting of ice reached a depth of from 60 to 70 meters, and the masses of sand and mud which the glacier rush carried with it were so extensive as to build out the coast line.

The first glacier rush happened an hour and a half after the eruption began, and flooded a sandy waste at the foot of Katla. Spectators saw the flood, overhung by steam and dust clouds, laden with gigantic icebergs, rushing down a valley, and in a short time the sea near by was covered with large and small bergs. At 5:30 that afternoon, a new glacier rush started in farther to the east, and continued most of the night, as shown by the roaring of the waters and the crashing and rumbling of colliding icebergs. This torrent spread out over a flat area of about 125 square kilometers, carrying thousands of ice slabs, the larger ones becoming stranded on the sandy waste. At one place the torrent rushed against a cliff 60 meters high, so that ice fragments and water shot into the air like a gigantic surf on a sea shore. By the next morning most of the flood was finished, but there were several smaller outbreaks on later dates. Farming lands were damaged, and many animals were killed. A visit to the crater after the eruption revealed heaped-up ash and great clefts 500 to 800 meters long, 40 meters wide, and 25 meters deep. Two great gorges had been eroded out of the glaciers by the floods.

The Lesser Antilles, consisting of numerous small islands arranged in a wide arc between Porto Rico and the South American coast, contain numerous volcanoes. In fact this island group is simply a chain of volcanic piles built upon the ocean floor sufficiently high to rise above sea level. Two of the islands—Martinique and St. Vincent, which are separated only by the island of St. Lucia—are surmounted by volcanoes that have become famous for their destructive violence. In 1902 these two volcanoes, Mont Pelée and La Soufrière, both of the explosive type, erupted almost in unison. Considerable time had elapsed since the last preceding disaster in the two islands; and the people, with that easy forgetfulness or fatalism so commonly shown in lands of volcanoes and earthquakes, had built settlements and established plantations on the slope of the two cones. As a result, the abrupt explosions of 1902 took a large toll in human lives.

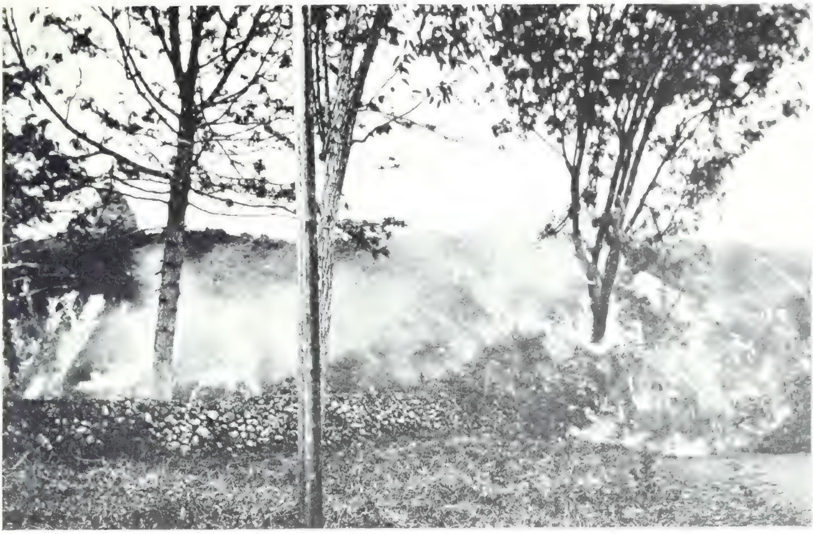
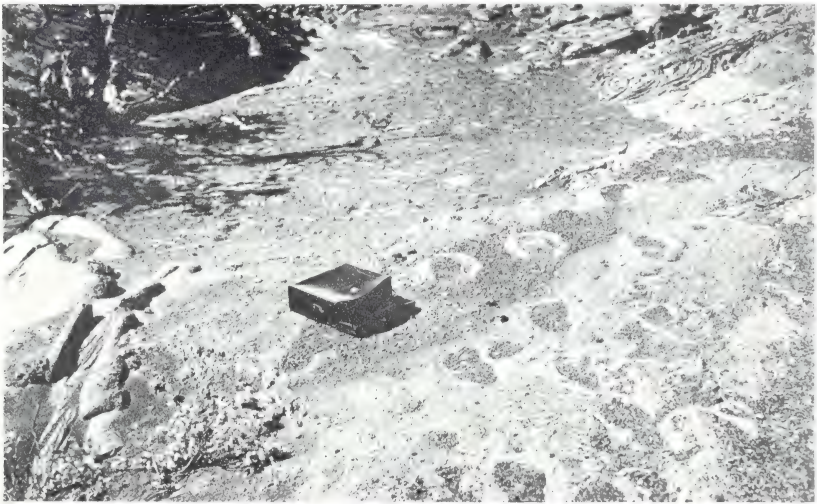


Photo Tai Sing Loo

A. ADVANCING LAVA FLOW

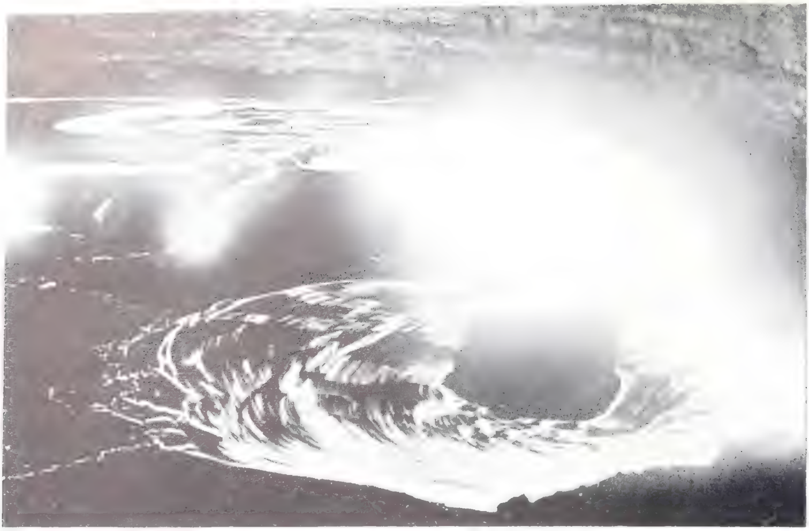
Flow from Mauna Loa crossing a stone fence and destroying trees. April 16, 1926.



Hawaiian Volcano Observatory

B. CLUES TO THE PAST

Footprints in hardened volcanic ash from the Hawaiian eruption of 1790. Many people lost their lives during this eruption.



Hawaiian Volcano Observatory

LIQUID FIRE

Night photograph of a lava pool on the floor of Halemaumau pit, Kilauea, 1923.

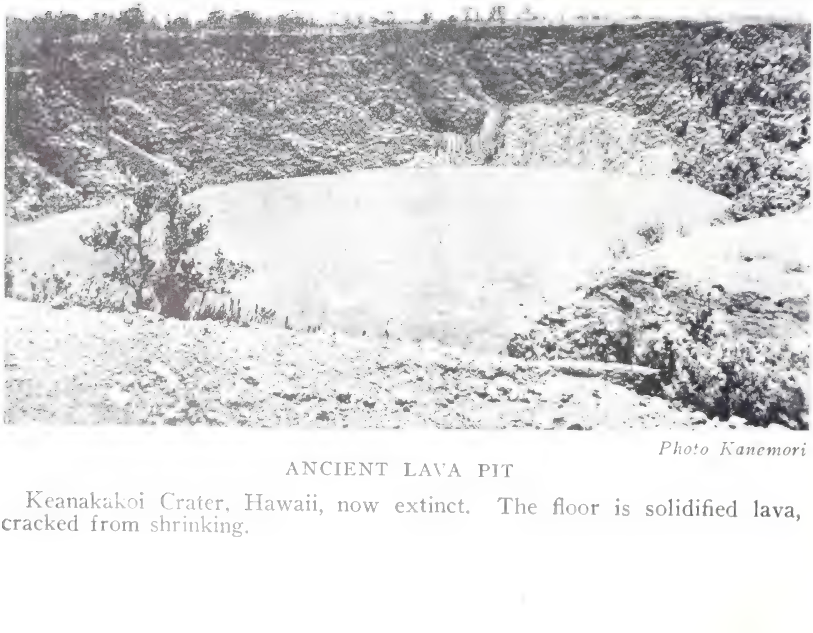


Photo Kanemori

ANCIENT LAVA PIT

Keanakakoi Crater, Hawaii, now extinct. The floor is solidified lava, cracked from shrinking.

Fortunately the eruptions and their effects were studied by several scientific men. The following quotations (Anderson and Flett, 1903, pp. 378, 380-381) give some idea of these magnificent but terrifying displays:

> ### The Eruption of La Soufrière, May 7th, 1902
>
> #### *Premonitory Symptoms*
>
> For 90 years the Soufrière had slumbered, and few were living who had seen it in eruption. But in the early part of the year 1901, an uneasy feeling began to arise in the minds of those who dwelt on the flanks of the mountain. Earthquakes are by no means infrequent in St. Vincent, though usually of slight severity, but in February and March, 1901, they became so numerous around the north side of the volcano as to awaken suspicion that danger was threatened. There are two settlements of Caribs—the remains of the original inhabitants of the island, most of whom were exported, after the close of the Carib War in 1796, to the island of Rattan in the Bay of Honduras—at Morne Ronde on the west, and at Sandy Bay on the northeast of the mountain. It may be that traditions linger among them regarding former disastrous eruptions, or superstitions connected with the crater, for though the Caribs are certainly not deficient in courage, they became so apprehensive that they petitioned to have their settlements removed to some other part of the island, and officials had to be sent to quiet their fears. There is evidence in letters written to the Kingstown newspapers in March, 1901, that general interest had been awakened, and it was widely known that anxiety was being felt regarding the condition of the volcano.
>
> In the latter half of April, 1902, the earthquakes increased considerably in number and intensity. At Owia, on the 13th of April, at 12:20 p.m., there was a sharp shock, and about that time as many as eight tremors were sometimes experienced

there in 24 hours, all slight and of short duration. Along the whole northeast quadrant of the hill the violence of the earthquakes in the last week of April, 1902, was exceptional. They dislodged stones from the cliffs of lava and sent them tumbling down the slopes, and occasioned small landslips in the loose material of the taluses, damaging the crops which were planted there. On Monday, April 29th, three well-marked shocks were experienced at Windsor Forest and Campobello, while at Morne Ronde about this time eighteen earthquakes were counted in one day. It will be remembered that the first signs of activity on Montagne Pelée were observed about the 23rd of April, and that a great earthquake shook Guatemala on the 18th of April. As yet the Soufrière had shown no symptoms of actual eruption. The Caribs at Morne Ronde, however, fully anticipating an outburst, were preparing to evacuate their houses and flee to Chateaubelair and other places of safety.

Preliminary Stages of the Eruption, Tuesday, May 6th

By 1 o'clock on the afternoon of Tuesday, the 6th of May, there could no longer be any doubt that the Soufrière was in eruption. It is said that during the previous night the Caribs had seen a cloud of steam emitted from the mountain and a bright glow on the summit. This is doubtful, but certainly on that morning they were flocking into Chateaubelair, and a general anxiety was awakened in the neighborhood.

At Wallibu a rumbling sound like distant thunder was heard from 6 to 8 a.m. on the 6th of May, and between 8:30 and 12 that forenoon, seven distinct shocks of earthquake were felt. These tremors were not experienced in Chateaubelair, which is about a mile further south. The day was very clear, and the whole lip of the crater could be perfectly made out by those on the south-west side of the hill. From the north side the crater is concealed by the intervening Somma wall, while the inhabitants of the windward quarter could see none of the upper parts of the mountain owing to the thick trade-wind cloud which covered them.

As the afternoon advanced matters got distinctly more threatening in appearance. The trade-wind cloud hovered as usual over the mountain, but the ridge on the south side of the crater was visible from Chateaubelair. About 4:30 p.m. a big column of steam was seen to ascend from it, and several observers remarked that at the base of this there was a red glow like the reflection of fire. About half-past 5 o'clock there was another outburst, and the red reflection from the cloud was again visible. At 6 o'clock a thick cloud of steam was emitted, and from Wallibu fire was seen forming a ring around the lip of the crater, and a crackling sound was heard, which sounded like "brush on fire." A general stampede ensued in the villages and plantations of Wallibu and Richmond, only a few remaining to look after their property and domesticated animals. The sun was now setting. In Chateaubelair all was animation and excitement. The little village was crowded with refugees from the western base of the hill, and the whole population was standing in the streets and on the beach watching the progress of the eruption. Mr. T. M. McDonald, who had received warning by telephone from his manager at Richmond Vale, that the Soufrière was emitting steam clouds, landed on the beach a little north of Chateaubelair pier at 6:30 p.m. He says: "The summit of the Soufrière was enveloped in the usual white cloud, and at first nothing unusual was visible. Within a minute or two of landing, however, one of the party exclaimed, 'Soufrière is bursting now,' and on looking toward the mountain I saw enormous vertical columns of white vapour being ejected, virtually noiselessly, and was now quite convinced that an eruption had been, and was now taking place."

At 7:30 p.m. a great explosion followed, accompanied by a loud noise and by slight earthquakes. The discharge of vapour was greater than any of those which preceded it. Mr. McDonald notes that he observed "flame along the whole line of the top of the crater, forming a thin red sparkling line between the base of the column of vapour and rim of the crater."

Thereafter at intervals of about two hours similar discharges took place, and some of them were reported to be also accompanied by flame.

The night and all the following morning were a time of apprehension and terror for the inhabitants of the island. It was evident that the activity of the volcano was increasing with each outburst, and the final catastrophe was only a question of time. It came in the afternoon, as told in the continuation of the Anderson and Flett account (1903, pp. 392-396) prefaced by graphic notes made by an eye-witness:

The Climax of the Eruption. The Descent of the Great Black Cloud

The climax of the eruption was now at hand. It came with terrible suddenness. With laconic brevity, Mr. McDonald records it as follows:

"1:55. Rumbling. Large black outburst with showers of stones all to windward, and enormously increased activity over the whole area.

"A terrific huge reddish and purplish curtain advancing up to and over Richmond Estate.

"At this stage left Richmond Vale House and hurried into and pushed off boat a few minutes after 2 p.m. Saw vapour as we rowed hard across Chateaubelair Bay coming down to sea level past Richmond Point. Sea peppered all round with stones, one of which—about a cubic inch—fell inside the boat, in which were eleven persons.

"The huge curtain referred to was advancing after the racing boat, which never seemed likely to get out of the range of it, or the falling stones, which latter varied from the size of one's fist downward. . . .

"The lightning and thunder at this time were terrific, and there were noises inland.

"Everything seemed to point to a general break up, both on land and sea."

This was the outburst of the great black cloud, which, charged with immense quantities of red-hot dust, poured from the crater and swept down the valleys to the sea.

It will be noticed that Mr. McDonald describes it as reddish and purplish. He does not enter into particulars as to its form, except that he states that it was like a curtain. All who have seen the side of this cloud use exactly the same term in describing it. It resembled a curtain hanging in folds, black, dense, solid, and well defined. The cloud swept out to sea over Richmond; its southern margin was over the headland on the south side of the mouth of the Richmond River. Richmond Vale House stands in the next valley to the south of Richmond Estate, and it was spared and but little damaged, while Richmond was wiped out and destroyed. Mr. McDonald's boat was perhaps half a mile south of the edge of the black cloud. Stones fell about it, but there does not appear to have been great darkness for some time after, and he does not speak of suffocating vapours or dust, or of any very great heat.

It is interesting to compare with Mr. McDonald's description the statements made to us by some coloured men, who were just a little further north than Mr. McDonald, and were caught in the edge of the cloud. They had been at Richmond to remove their personal belongings to Chateaubelair, and their boat was returning when the black cloud swooped down.

The sea was perfectly calm and the day clear, though there had been a few drops of rain in the forenoon. The boat had just rounded the point south of Richmond River, and was on the north side of Chateaubelair Bay. The cloud struck them like a strong breeze, though, being under the shelter of a high spur of land, they did not feel it much. Still it came over the water with a strong ripple and a hissing sound, due to the hot sand falling into the sea and making it steam. In a moment it was pitch dark and intensely hot and stifling. The cloud was highly sulphurous, and this irritated their throats and nostrils, making them cough. The heat was terrible and the suffocating feeling very painful. They threw themselves into the sea to escape burning by the hot sand. It does not appear that the surface of the water was boiling as it was in some other cases. They all dived, and when they returned to the surface the air was still unfit to breathe and the heat intense. So they continued to dive repeatedly, but when they came up again the air was almost as bad as before. How long this lasted they cannot tell, but they thought it might have been several minutes. At last they were utterly exhausted and could have held out no longer; then they felt the air clearing, the heat diminished, though still very great, and they clung to the boat for a few minutes before they were able to get into it again.

One man was not so good a swimmer as the others, and his strength was soon exhausted. He held on to the gunwale of the boat and took the risk of burning rather than of drowning. He described to us the insufferable heat and the sulphurous smell, and he was rapidly becoming unconscious when the air cleared. The sea around was hissing, and it was so dark that two men hanging on to the boat, side by side, could not see one another, even though they could touch. There was a continuous loud noise, but a person speaking in an ordinary tone of voice could easily make himself heard. This is a curious fact, for the report of this explosion was heard at Barbados. But Mr. McDonald confirms the statement. He noticed particularly that when he gave orders to his men to launch the boat and leave the shore, he did not require to exert himself in the least to make them hear him.

While this man remained clinging to the gunwale the hot sand rained upon him. His woolly head was wet and the sand was cooled by contact with it, but it gathered above the lobes of his ears, and there the heat was sufficient to dry his skin and produce painful burns. He told us that when the cloud had passed there was enough sand on his scalp to fill his hat twice over. It formed a layer 2 or 3 inches deep. The ash fell dry, there was no rain and no scalding mud. When they got back into the boat they found it nearly filled with fine ash and stones, and these were so hot that had the boat not been leaky and partly filled with water it might have taken fire. Yet these men were only in the outer edge of the cloud. A few hundred yards further north this cloud deposited in some places 40 feet of red-hot sand in a few minutes. It was for this reason also that they experienced no great shock when the cloud struck them, and did not feel it pass like a strong blast, for Mr. McDonald states, a cloud came down with a high velocity. His boat was going at perhaps 8 or 10 miles an hour, impelled by the frantic exertions of a crew fleeing from a dreadful death. But the cloud was travelling at least twice or thrice as fast. The curtain-like lateral margin of the dense black cloud was almost stationary, or consisted of gentle eddies at the side of a rushing torrent.

In the Carib country work in the fields had stopped, and in the sugar works, though they were full of people, no sugar making was going on. Everyone was watching the progress of the eruption in mingled fear and admiration. Small stones began to fall after mid-day, and about half past one in some places there were showers of hot scalding mud. The cattle, horses and mules were mostly out grazing, but nearly all the people had gathered into the most substantial buildings, the managers' houses or the stores and cellars attached to the sugar works, though many were in their huts in the villages adjoining the estates. Some had been struck with falling stones, but as yet probably no one was killed, and but few injured.

Then, with a loud roar, at 2 o'clock the great convulsion came. Those who were in the open air saw the huge black cloud rolling down the mountain in globular, surging masses. They fled into the houses and shut the doors. Onward it rushed with a loud rumbling noise and filled with lightnings. Any who were in the open air perished at once. Many of the negroes' huts were so densely crowded with people, that there was hardly standing room. At Lot 14 the manager and his wife had shut themselves up in the rum cellar below the house, and firmly closed all doors and windows. They had a terrible experience, but they survived. All of those in the house itself or in the negro village were killed. It will be understood that as the tropical houses are so built as to secure free entrance of air, it is almost impossible to close them up securely, and the suffocating blast reached the interior and stifled all who were there. All the animals in the fields also perished.

The Avalanche of Dust, Sand, and Stones

(Anderson and Flett, 1903, pp. 447-448)

The distribution of the materials emitted during this eruption on the Soufrière and in the valley at its base, cannot fail to be regarded as very remarkable, and cannot be accounted for on the theory that the ash was simply rained down from above and gathered where it fell. A rain of ashes certainly took place. It lasted for hours on Wednesday afternoon and night. Hot stones falling from the sky struck many people in the Carib Country who were running from one house to another in the gloom, seeking their friends, and the noise of the ash clattering on the roofs was at times almost deafening. In this way a sheet of deposit must have been laid down all round the volcano, which thinned out gradually as it was traced further and further from the crater. Over Chateaubelair and Georgetown the black cloud did not pass, and the thickness of the ash is a measure of the violence of the shower. Since 18 inches accumulated in Georgetown, it does not seem unlikely that the 3 feet or more of deposit in the Carib Country, and the 5 feet on the Mahoe, above Lot 14, should be due almost entirely to the hailstorm of sand and scoria which lasted through the night. Over the Carib Country the great black cloud rolled, but we cannot believe that it piled up any considerable sheet of ashes, though we know it was laden with dust, as some of the survivors state that on the floor of the huts a thickness of 1 or 2 inches gathered during the passage of the wave of heat which killed so many people. Similarly, we may allow that the ash which lay on the ridges and slopes of the spurs, on the mountain and on the edge of the crater, which had originally varied in depth from a few feet up to 10 or 12 feet, might have been entirely deposited during the rain of ashes. But this will not account for the extraordinary manner in which the ravines were choked with hot sand. The very high temperature of these masses shows that they did not gradually accumulate, but must have been practically instantaneously piled up in the valleys. So fine is the dust that it would have fallen very slowly had it been projected vertically upwards from the crater, and should in that case have been nearly cold before it reached the surface of the ground. It would probably also have shown traces of stratification, as after each outburst the coarse stones would first fall and the finer material would settle slowly afterwards. But on the banks of the Wallibu and Rabaka Dry River it was rare to see sections of the new ash which exhibited any pronounced stratification. The whole mass—sand, stones, scoria, and burnt timber—seemed to have reached its present position practically simultaneously.

The Hot Blast

(Anderson and Flett, 1903, pp. 450, 452-453)

Few in St. Vincent saw the avalanche and none of these survived; but many were struck by the hot blast, and of these a certain number have lived to tell the tale. Its force was nearly spent before it reached the low grounds of the Carib Country, where stood the most populous estates, but there and in Fancy the men who were holding the doors or windows felt the shock, and in one or two cases were knocked down by the impulse of the blast. The houses are built so as to freely admit the air, and the labourers' huts cannot be effectively shut up. Several of the survivors in Overland Village and Orange Hill told us that the sudden rush of the hot gases was like a powerful puff of wind. It is only, however, further up the mountain that it was sufficiently vigorous to leave behind unmistakable effects.

At Richmond and at Rabaka it was travelling at perhaps 30 miles an hour, a strong breeze, but not sufficient to do much damage. The trees were broken by the falling stones, and the weight of ash which gathered on the branches and the withered leaves was often sufficient to weigh them down to the ground or tear them off the stems. It was not the violence of the blast which injured the vegetation.

In short, the effects of the hot blast were shown by all the area over which the great black cloud had swept in the first part of its course, and the correspondence between the region of broken forest and the country covered by the black cloud before it reached the lower grounds is too close to be accidental. When the dust in the cloud was hot and when the velocity of the gases was still very great, the forest had been cut down and the wood charred, eroded and destroyed. When the hot sand had cooled and was subsiding, the hot blast effects diminished and finally disappeared, though still the cloud of dust and asphyxiating gases crept along the ground, and where it passed over the estates on the windward shore, though no longer able to cut down or overturn the trees and structures in its path, brought injury or death to their living occupants. To those who saw it from the outside it was a black cloud, or even a purplish and reddish cloud, but those who were overtaken by it felt it a hot blast laden with sand and dust. This was near the shore, or on the sea; only there did any who were caught survive. No one in St. Vincent was in the region of its fiercest energy, but in the city of St. Pierre a similar blast wrought desolation with a completeness and a murderous violence which are now a matter of history.

But the blast is not merely a phase of the great black cloud, it has also a very close relationship to the avalanche of sand. In it the gases greatly preponderated; it had a mobility, a power of surmounting obstacles, a tendency to spread laterally which the avalanche does not seem to have possessed. We may say that the hot blast coursed over the ground like a current of heavy gas; the avalanche resembled a viscous heavy fluid. The blast which swept down into the valleys at the south side of the Soufrière was too heavy to climb vertically the steep face of the Morne Garu. It split into two parts, one of which ascended obliquely over each shoulder of the mountain, mowing down the forest and strewing the trunks of the trees before it in such a way as to mark the direction of its path. The avalanche, on the other hand, when it reached these valleys turned almost at a right angle to its previous course and flowed along them, clinging to the ravines, but did not ascend the opposing slopes. Except in this case there is little evidence that the blast had any power of climbing; it seems, in fact, to have been so heavy, so weighted down with dust that it flowed along the depressions of the hill sides almost like a torrent of water. This is shown by the evidence of those who saw the black cloud pouring in an inky mass down the gorges on the leeward side of the hill. The Carib Country is too level and open to modify in any way the course of this current, but at Chateaubelair there are several well-marked ridges between the village and Wallibu, and these certainly directed and deflected the path of the blast. At the north side of Richmond Vale Estate there is a spur, some 500 or 600 feet high, running down to the sea, and on the side of this ridge next the crater the destruction of vegetation has been very great; on the south side, a week or two after the eruption, everything was as green as before. It is in every way probable that these ridges saved the village, and a careful examination of the difference in the appearances presented by the country to the north and to the south side of each of them convinced us that they had intercepted the violence of the blast, and protected the region behind them. The moving mass of sand and gases was too heavy to rise freely in the air when it passed over Richmond, but clung to the surface of the ground, and lost much of its energy and dropped most of its solid matter before it could surmount an obstruction. The blast was, in fact, only the lighter and upper portion of the avalanche of dust.

The rampart of the Somma wall, which faces the crater on its northern side, undoubtedly protected the country behind it, for the denser portion of the cloud was too much loaded with dust to climb this ridge. Its main force poured over the lower south lip of the crater with the avalanche of sand. On the north side the deposits are comparatively thin, and it seems that most of the material that emerged from the crater was deflected by the Somma and lodged in the valley of the Larikai. A black cloud certainly descended on Grand Baleine, but in surmounting the intervening summit ridge of the hill it had lost by far the greater part of its burden of ash and therewith most of its violence.

Pelée is a more familiar name than La Soufrière. At one blow the great volcano on the Isle of Martinique annihilated a populous city. This destructive eruption of Pelée, which came almost simultaneously with the outburst of La Soufrière described above, has also been recorded graphically by Anderson and Flett. Parts of their description (1903, pp. 481-483) follow:

The only previous eruption of Pelée of which there is historic record is that of 1851, which appears to have been brief and abortive. A few mud-flows in the rivers, a discharge of steam and a fine ashy dust, and the volcano relapsed into quiescence for another 50 years. The earlier stages of the eruption of this year were of a precisely similar character, and this was one of the causes which lulled the suspicions of the inhabitants of St. Pierre, and inspired them with a fatal feeling of security. The premonitory earthquakes, so frequent always at the Soufrière, where they have heralded the outburst of every eruption, and prepared the minds of the inhabitants for the approaching paroxysm, were apparently practically absent in Martinique, and although there are records of a few small shocks, we are not aware that they were numerous or disquieting. But at Pelée there was a long preliminary phase leading up to the crisis. Steam was seen to ascend from the crater about April 23rd, or a fortnight before the culmination of the eruption. At first the activity was so gentle that it awakened only curiosity, and several people made ascents and reported that both the upper and the lower Étangs [pools] were boiling and giving out much steam. But day by day the violence increased, and by May 2nd a good deal of apprehension was felt in St. Pierre, and some were meditating flight. That night there was great activity in the craters, loud noises were heard, and over the mountain top a bright glare was visible. The ashes were wafted by the wind over St. Pierre and Prêcheur, and next morning these were covered with a layer of light grey dust. The crops were blighted, the cattle starving for want of water and of food; the people from the country began to flock into town. The noises and the rain of cinders and of dust continued more or less intermittently from that time onward.

The river descending to the south-west from the summit had already become muddy on more than one occasion, but on the 5th a great flow of hot mud poured down the Rivière Blanche with great rapidity and overwhelmed the Usine Guérin, killing many people. At the same time there was a small sea wave which did no damage. This mud-flow was apparently the waters in the Étang Sec which had escaped through some fissure on the south side of the peak, driven out by the ascending column of lava and the constantly increasing pressure of the gases within the volcano. Next day the streams were still torrents of mud, and the harbour of St. Pierre was covered with floating trees and the wreckage of bridges and other structures swept away by the floods. No better instance could be cited of the difference between Pelée and the Soufrière in the rapidity with which the crisis of the eruption came than this: in Martinique the discharge of the crater lake took place four days before the climax arrived; at St. Vincent the first overflows were seen only three hours before the avalanche of dust swept down the mountain slopes.

From May 2nd onwards, no doubt remained that the volcano had resumed activity, and as each day passed the outlook became more threatening, the discharges of steam more violent, the detonations louder, and the rains of ashes more frequent and heavier. On the 4th the cloud of dust was so thick over the leeward side of the mountain that the steamer *Topaze* could not call at Prêcheur. The ash was very fine and light grey, resembling cement or flour, and covered the trees and shrubs as if there had been a light fall of snow. Animals were dying of thirst and hunger; birds, overcome by the fumes, or weighted down by the dust on their plumage, were lying dead by the sides of the paths; the crops were withering, and the outlying districts already abandoned and deserted. On the 6th, and again on the 7th, loud noises rose from the crater, and the red glare was visible in the steam cloud. But as yet no earthquakes: even though a rift could now be seen to have opened at the base of Morne Lacroix.

Wednesday, May 7th, the day of the great eruption of the Soufrière, was not marked by any special features in Martinique.[1] That day the mountain was, in fact, rather less violent than it had been on the 6th; but on the following morning, at 7:50, the great convulsion came, and with it the end of all things for St. Pierre.

So deadly was the blast that swept the city, so awful in its completeness the destruction that it wrought, that few survived who saw the great black cloud descending from the mountain, but of those few there are some who have placed on record what they saw, and it is clear from their descriptions that in Martinique there was a repetition of what had happened in St. Vincent on the previous afternoon. The mountain burst open and a great cloud appeared near its summit. It arose with a loud, growling noise, and some say that in it they saw a bright red glare. Like an avalanche it poured upon the city, covering the distance in a few minutes, and enveloping all in total darkness. It passed almost as rapidly as it had come, and when the darkness lifted a little, it was seen from the ships lying in the harbour that the city was razed, and fierce fires had broken out in many places. The north end of the town was practically wiped out in an instant; nothing was left but blazing ruins, the inhabitants perished where they stood. But in the south end the devastation was not so complete, the walls were left standing in many of the houses, and the living occupants rushed into the streets, yelling with pain and terror, terribly injured, throwing themselves into the sea to mitigate the agony of their burns. It was no earthquake that levelled the town, neither was it lightning nor the weight of ashes. All who saw the calamity and have survived agree that a mighty blast came with the cloud and mowed down everything in its path. The origin of the conflagration is not quite so clear, and there may have been more than one cause. Lightning may have ignited some structures, and the fires in some of the houses may have played a part in setting the ruins ablaze. But the cloud was filled with hot ashes, and we have no doubt that, especially in the north end of the town, the temperature of the dust was sufficiently high to ignite combustible substances.

---

[1] In the "Report of the Commissioners of the Academy of Sciences," it is remarked that a tidal wave was observed on the 7th May both in Martinique and Guadeloupe, and that it did not correspond to any eruption (of Pelée); needless to say that was the day of the great eruption in St. Vincent.

Captain Freeman, of the *Roddam,* has described his fearful experiences in language so terse and vigorous that it is well suited to the occasion:

At about 8:15 he was in the chart room; a good many of the sailors were leaning over the side of the vessel watching the distant mountain, which was emitting dense clouds of smoke and occasional flashes of light. Mr. Campbell was talking to Mr. Plissonneau on the deck. On a sudden he (the Captain) heard a tremendous noise, as though the entire land had parted asunder. Simultaneous with the noise there was a great rush of wind, which immediately agitated the sea, and tossed the shipping to and fro; he rushed out of the chart room, and looking over the town and across the hills he saw a sight he cannot describe. He remembers calling out to Mr. Campbell, and saying: "Look!"—then an avalanche of lava[1] was upon them. It immediately caught the town afire as it passed over it, likewise the shipping. It struck his ship with the force of a mighty hammer, and the lava [1] rained upon the deck. Everyone, as far as he could see, sought shelter at once, but the heat was so great, and the air so suffocating, that Mr. Campbell, and many of the crew, among whom was the chief mate, threw themselves in despair overboard. Some crawled from where they had hidden themselves on to the deck to obtain a breath of air, and were roasted upon the fiery hot ashes. He did not lose his head, his first thought was to try and save his ship and such of his crew as were still alive. He rang the bell for full speed astern, and the heroes below turned on the steam. He had time to slip his anchor, and he was off. As his steering gear was rather difficult to manage he once or twice nearly ran foul of the steamship *Roraima,* which was on fire. He saw two still figures standing on the bridge with arms folded heroically awaiting their end. One of them waved a good-bye to him. There were a good many passengers on board, and these were rushing up and down in anguish. When he was steaming out of port he looked down at the burning city. A pall had enveloped it, but through it he could plainly see the skeletons of burning houses, and the shadowy figures of men and women running hither and thither in their terror, and above the loud din of the falling cinders, the roar of the raging sea, he heard the agonized cries of 30,000 voices.

---

[1] This is, of course, an erroneous use of the term *lava.* No doubt the Captain had in mind the ash and cinders of the cloud.—Ed. Note.

The close study of La Soufrière and Pelée in 1902 increased our knowledge of explosive volcanoes in general; but it also emphasized certain peculiarities of these two Antillean representatives of the type. These unusual characteristics are summarized in the following excerpts (Anderson and Flett, 1903, pp. 499-500, 523):

The attention of mankind has this year been powerfully directed to the effects produced by eruptions of a type which hitherto has not been known to exist, and which differs from other more customary kinds of volcanic action in several important respects. As the catastrophe by which, in the month of May, 1902, the city of St. Pierre was erased from the map of the world will remain to all time a witness to the violence with which these eruptions are attended, we propose to adopt the term "a Peléan Eruption" to designate this group of phenomena. The earliest historic instance of such eruptions is that of St. Vincent, in 1812, which, as we have already shown, was clearly accompanied by the discharge of vast masses of hot sand and stones into the valleys of Wallibu, Larikai, and Rabaka. It is probable, but it is not certain, that the eruption of the same volcano in 1718 was also of this nature.

---

[1] This is, of course, an erroneous use of the term *lava.* No doubt the Captain had in mind the ash and cinders of the cloud.—Ed. Note.

Eruptions of the Peléan type are distinguished by the occurrence of one or more discharges of incandescent sand, which rush down the slopes of the mountain in the form of a hot-sand avalanche, accompanied by a great black cloud of gases charged with hot dust, which sweeps over the country with a very high velocity, mowing down everything in its path. All living beings within the zone nearest the crater are killed; all plants reduced to charred and broken stumps. At greater distances men and animals are scorched by hot sand or mud; plants are burnt, eroded, and stripped of leaves and branches; but beyond the limits covered by the great black cloud no effects are produced, other than those consequent on the rain of ashes which precedes or follows the avalanche. Except for the dust avalanche, there is nothing unusual about these eruptions. They have, indeed, many points in common with those of volcanoes of the ordinary explosive type, to a sub-group of which they evidently belong.

We have seen that the magma of these Antillean volcanoes, or at least the uppermost part of it which gave rise to the great black cloud, was to a large extent crystallized, contained comparatively little fluid matter, and that it was accordingly near the temperature of consolidation, or may even in part have solidified already. These may all have been powerful factors in determining it to assume the form of a dust cloud as soon as the retaining pressures were relieved, and the vast quantities of steam and other gases it contained were free to expand.

But the chemical aspects of the problem must not be neglected; they may be of even greater importance than the physical. Both magmas are andesitic, but the analyses and microscopic investigations which have already been published make it certain that they are not exactly the same, so that it does not appear likely that the dust-avalanche type of eruption is a consequence merely of the presence of a magma with a certain narrowly restricted chemical composition.

On the other hand, it is a significant fact that many of the most terrible instances of disastrous and sudden volcanic explosions have been furnished by volcanoes emitting hypersthene andesite. Krakatoa and Bandaisan are two examples of quite recent date. This group of rocks is, of course, a very diverse one, and includes many important variations; but as contrasted with the basalts, which in so many cases give rise to floods of liquid lava quietly welling out of craters or fissures, they seem predisposed to violent and disruptive activity. The rarity of dykes in St. Vincent, and the abundance and thickness of the sheets of coarse agglomerate, point to the same conclusion.

Additional light is thrown on the character of La Soufrière and Pelée by the following notes (Hovey, 1902, pp. 323-328, 342-349) made by an American geologist shortly after the great eruption:

The Soufrière, and, in fact, the whole of the island of St. Vincent, is made up of ancient lava flows alternating with volcanic fragmental deposits or tuff agglomerates. These ancient agglomerates show that there have been many eruptions of the volcanoes of St. Vincent of the same character as that of 1902. They contain bombs as well as blocks. The beds of solid rock on the island show that many of the ancient eruptions were accompanied by extensive flows of molten lava. The porous agglomerates have suffered much from the decomposing action of percolating waters, and the lava beds show extensive alteration due to the same agency. Beautiful spheroidal weathering is common in the basalts of the southeastern part of the island and in the elevated beach conglomerates of the windward coast.

Although there are many ancient lava beds in the composition of the mountain, no *stream* of melted lava has issued from the Soufrière during the present eruption. The "bread-crust" bombs, however, which occur plentifully on the mountain sides, especially on the windward slopes, show that during the present eruption molten lava has been present in the throat of the volcano, and that many lumps of half-melted rock were thrown into the air. Besides the bombs, the volcano ejected blocks of ancient andesitic lava of several kinds and of varying degrees of coarseness of grain, and of all sizes up to masses six or eight feet across, and vast quantities of coarse and fine lapilli and dust. Most, if not all, of the blocks were thrown out at very high temperatures, as is shown by their cracked condition, though they were not actually fused. Although a few bombs, some of which were twelve to fifteen inches across, were found on the leeward side as far away from the crater as the site of Richmond village, three and one-half miles distant, by far the largest number of both bombs and blocks, as well as the largest specimens, were found on the windward side, bombs fifteen to eighteen inches in diameter being common in the bed of the Rabaka Dry River.

The area of devastation on St. Vincent is very large in proportion to the total area of the island. After plotting it out carefully on the British Admiralty chart and measuring the area with a planimeter, I find it to be forty-six square miles, practically one-third of the entire area of the island. From much of this devastated area, however, the ashes are being washed off so rapidly by the rain that vegetation is already asserting itself, and within another year crops will be growing there again.

Extensive landslides have taken place on the western side, removing a strip of coast, in places one hundred yards wide, continuously from the mouth of the Wallibou River to Morne Ronde village, a mile and a half to the north, and at intervals for two miles farther north. These landslides have left precipitous walls along the shore-line, and deep water is found where villages stood and prosperous plantations existed before the eruption. We had no sounding line, but our boatmen could not touch bottom with a twelve-foot oar three feet from shore on the site of Morne Ronde village. The sections left by the slides show that the land which has disappeared consisted of delta and coast-plain deposits, material which would easily be shaken from the more substantial lava flows and agglomerate beds by the vibrations due to the eruptions. The eastern, or windward, side of the island is not nearly as steep as the leeward, and landslides have not occurred there as features of this eruption. On the contrary, the windward shore-line from Black Point, a mile south of Georgetown, northward almost to Chibarabou Point, more than six miles distant, has been pushed out by the vast quantities of fresh lapilli which have been brought down from the slopes of the volcano by the rivers and the heavy rains, during and since the eruptions, and distributed by the ocean currents.

A large amount of material, too, was brought down by the Rabaka Dry River an hour in advance of the great outburst of May 7, which seems to have been due to the bodily discharge of a portion, at least, of the old crater lake into the headwaters of that stream. Survivors who attempted to cross the Rabaka Dry River toward noon of that day report that they were prevented by a torrent of "boiling hot" water and mud rushing down the valley, and that a wall of water and mud fifty or more feet high (they compared it with the height of a factory chimney) came out of the upper reaches of the river and swept out to sea. There was no heavy rain that day before the eruption took place, but the lake still was in the crater early in the day, according to the tale of a fish-woman who had ascended the mountain from Georgetown that morning on her way home to Chateaubelair. The trail led along the rim of the crater for half a mile. The woman reached the rim at nine o'clock and found that fissures had appeared in the ground and that the lake was at a higher level than usual and boiling. She rushed back to Georgetown to warn the people, but her tale was discredited. Mr. MacDonald's notes contain the entries: "12:55 p.m. Enormous discharge to windward side, color darker. 1 p.m. Tremendous roaring, stones thrown out to windward thousands of feet." While this does not *prove* the bodily outthrow of the lake, it shows that there was a great outburst from the crater just in advance of the flood in the Dry River Valley.

It is evident that there was a blast or a series of blasts of hurricane violence from the crater of the Soufrière as well as from that of Mt. Pelée, as a feature of the eruptions of 1902. The effects were not so appalling, however, on St. Vincent as on Martinique, because no large city was destroyed there. The overturned trees constitute the principal evidence on the island of St. Vincent. They all point away from the crater, except for slight modifications due to local topography. The blast extended radially in all directions from the crater, suggesting the explanation that some great volume of steam, rising from the throat of the volcano, could not find room for expansion upward, on account of the column of steam and ashes which had preceded it, and the ashes falling therefrom, and that it expanded with explosive violence horizontally and downward, following the configuration of the mountain. This accords with the testimony of Mr. MacDonald and other eyewitnesses of the eruptions, who say that they saw the clouds of "smoke" (dust-laden steam) rushing down the sides of the mountain with terrific speed. This dust-laden steam was able to do much work of erosion, as is shown by the horizontally scoured sides of some of the exposed cliffs and by the trunks and roots of trees. The roots particularly have been charred by the heat and have been carved into fantastic, pointed shapes, as if they had been subjected to the action of a powerful sand-blast. Erosion has not materially affected the original surface of the ground as yet, because almost everywhere one can find the living roots and charred blades of grass, and other vegetation beneath the covering of dust and lapilli, the first of which acted as a protection against the heat of the rest. Now, however, the heavy rains take up vast quantities of the loose lapilli for use as a powerful scouring agent in attacking the denuded hillsides, and thus old valleys are being deepened and widened.

The particular feature of the May eruptions of the Soufrière was the enormous amount of dust which was thrown into the air and distributed over a vast circle or ellipse the area of which cannot yet be calculated for lack of data. The British steamer *Coya* had an eighth of an inch of volcanic dust from this volcano fall on her deck when she was two hundred and seventy-five miles east-southeast of St. Vincent. The steamer encountered the dust at 10:30 p.m., May 7, eight and one-half hours after the eruption of the Soufrière began, indicating transport against the prevailing surface wind at more than thirty-two knots per hour. Reports of vessels from the west (leeward) of the island are curiously lacking. The dust was spread like a gray mantle over the island, generally diminishing in thickness from the crater outwards, but collected in vast deposits in certain valleys on the sides of the mountain, where the conditions seem to have been particularly favorable. The chief of these beds were formed in the Wallibou, Trespé, and Rozeau valleys on the leeward side, and in the valleys of the Rabaka Dry River and its tributaries on the windward slope, with by far the greatest thickness along the Wallibou and Rabaka Dry rivers. In the valley of the Wallibou the deposits were not less than sixty feet deep in places, while in the Rabaka Dry River the fresh material filled a gorge which is said to have been two hundred feet deep before the eruptions began. From a distance this deposit looks as if it were a glacier coming out of the mountains.

Such great accumulations of hot lapilli and dust retain their heat for a long time and they have given rise to secondary, or superficial, eruption phenomena of striking character and considerable interest. The river water and the water from the tropical showers percolating through the beds have come into contact with the still highly heated interior, causing violent outbursts of dust-laden steam. We saw one of these outbursts from the Wallibou Valley send up a column of such vapor fully a mile in height. The action lasted for nearly an hour. The secondary eruption . . . took place on a clear, dry morning and must have been caused by the percolating river waters. On May 30 we witnessed the throwing of a dam across the stream and the formation of a temporary lake by a heavy secondary outburst of dust-laden steam from the lapilli-bed in the Wallibou Valley. . . . After the eruption ceased the little lake soon rose to the top of the dam and quickly cut its way down to the old level, sending a "mud-flow" down the gorge to the sea. Such a lake in the valley of the Rabaka Dry River cut its new outlet through a narrow ridge of the old agglomerate constituting the wall of the canyon, forming as it did so a beautiful series of channel-bowls, pot-holes and scratched corkscrew channels.

When we first reached St. Vincent, the dust, especially that covering the Richmond estate, showed in marked manner the wind-drift surface so familiar in the case of freshly-fallen snow, and in many places these drifts were from three to four feet deep. There were several heavy rains between May 24 and 29, so that the appearance of the surface was very different on May 30 from what it was when I first saw it. Its drifted character was not nearly as evident, and the beautiful dendritic drainage, which was already in evidence on May 24, had been greatly extended and intensified. Geological operations, which under ordinary conditions are performed so slowly as to be imperceptible, were being carried forward rapidly under our very eyes. One item of interest was the action of the Wallibou River itself under the influence of the loose dust and lapilli along its banks. Its waters became so overloaded with sediment that they could only flow in pulsations, showing that intervals of time were needed by the stream to gather strength to force its way along with its load. On May 24 these waves or pulsations were from fifteen to forty seconds apart. Such mud streams carried large bowlders down the river bed to the sea.

Eruption of Pelée

The history of the present series of eruptions may be epitomized somewhat as follows: the gradually returning activity of the volcano began to make itself very manifest in the latter part of April, since visitors to the crater found warm water in the basin of the Étang Sec on the 25th of that month, and the lake was deep. Columns of dust-laden steam rose from an opening within the old crater on the east side of the Étang Sec and from one on the west side of the same basin, and cones rose about these openings. Water in large quantity collected in the old lake basin, assisted, perhaps, by a dam formed across the gorge by the ejecta from the western crater. The water was heated by the action of volcanic forces. On May 5 the heated waters of the crater broke through this dam and rushed, as a deluge of mud and bowlders of all sizes, down the gorge of the Rivière Blanche, and overwhelmed the Guérin sugar factory, which was situated at the mouth of the stream. On May 8 began the series of great explosions which have sent steam, laden with sulphurous gases, dust, ashes and stones, again and again over the southwest slope of the mountain with the violence of a tornado, several times reaching to St. Pierre and beyond. The author would explain the blasts in the same way as in the case of St. Vincent, but the great gash in the side of the crater of Pelée and the position of the neighboring ridges concentrated the force of the explosions in a certain direction and along a comparatively narrow zone—and the city of St. Pierre with its 26,000 inhabitants and thousands of refugees lay in an amphitheatre, a regular *cul-de-sac,* directly in the path of the blasts.

There seems to be no crater or center of primary eruption in the gorge of the Blanche below the great crater, or in the gorge of the Sèche, but there has been much secondary action along the lower portion of their courses, and much steam, with or without large quantities of dust, has been thrown high into the air, when water has reached the heated interior of the vast beds of volcanic ash deposited there during this eruption. Mud-flows and torrents have been very numerous down the gorges of these streams and on the plateau between them. Some of these flows have come directly from the crater, especially in the case of the Blanche; others have originated on the exterior slopes of the old cone, while others have started in the heavy ash-beds in the gorges in the manner already described in connection with the Wallibou River, St. Vincent, and the Falaise River on the eastern side of Mt. Pelée. . . . Subsequent rain has washed the fine mud from the stones.

These streams of mud and stones present some characteristics which distinguish them clearly from the surfaces of undisturbed ash-beds. The most striking of these is the existence of curved folds or wrinkles transverse to the direction of flow of the stream. . . . The plateau between the Des Pères and Roxelane rivers, on which was located the Fort Quarter of St. Pierre, was covered with several feet of wind-drifted ash, and it was not a mud-flow, or a series of mud-flows which destroyed this portion of the city, as has been stated in several publications.

In addition to the showers of dry dust and ashes, there fell during the eruptions an immense amount of liquid mud which had been formed within the eruption cloud through the condensation of its moisture. This mud formed a tenacious coating over everything with which it came in contact. That drops of mud, too, formed in the air and fell as a feature of the eruption is proven by the condition of the walls of the houses in Prêcheur, on which I found flattened spheroids of dried mud which could have formed only in the manner indicated. These flecks of mud were two, four and even six inches across, where two or more had coalesced. They occurred mostly on the northern and eastern walls of the houses. The testimony of the people as to the occurrence of rain during the great eruptions is conflicting, but the existence of this coating and these drops of mud proves that much aerial condensation of steam accompanied the outbursts.

During the latter part of our stay on the crater rim on June 24 the rain fell in torrents, and the deluge continued until we reached the foot of the outer cone on our return journey, the heaviest portion of the storm lasting for an hour or an hour and a half. Here we found the fumaroles sending out more steam than they did on our upward journey. When we crossed the Sèche River, we found a foot and a half of yellow, muddy water in place of the two or three inches which we had noticed there in the morning. We had not climbed out of the lowest gorge of the river before our attention was attracted by the heavy eruption that was taking place from the crater, and that was sending enormous clouds of dust-laden steam down the gorge of the Blanche to a point below the so-called Soufrière crater. Thunder-like noises nearer at hand had already made themselves heard and in another minute a wall of hot water, ten or fifteen feet high, swept with railroad speed over the place where we had crossed the river, and rushed on to the sea. The roar of the torrent was like that of a train, and the water dashing from side to side of the narrow gorge caused the ground on which we were standing to tremble like a ship when her propeller "races." The water was thick and as black as ink with its load of volcanic ash, and it transported with ease bowlders five feet in diameter which it had excavated from its banks. In many, if not most instances, these bowlders were the ejecta of the present eruption. To the left a stream of thick, yellowish mud was flowing down from the plateau of the Sèche-Blanche which we had left a quarter of an hour before and was cascading into the Sèche directly beneath us. Soon the black torrent cut into the ash-beds along its banks sufficiently to reach their still highly heated interiors and cause columns of steam to shoot hundreds of feet into the air. The steam columns carried great clouds of black and light-brown volcanic sand scores of feet upward. The hot area of the plateau also was sending skyward great columns of steam, and the whole formed a scene seldom witnessed, difficult to describe, and never to be forgotten. The next day we measured the gorge and found that the Sèche had deepened its channel at least ten feet in the loosely compacted recent ash during the hour which the flood lasted.

In this instance it seems evident that there was close connection between the heavy rain, the eruption, and the black torrent. Two explanations present themselves for consideration: (a) the crater may have thrown a mass of accumulated rainwater and ashes bodily over into the head canyon of the Sèche; (b) the rain which fell into the crater may have been the exciting cause of the eruption, but the mud-torrent may have been due to the soaking of the heavy coat of ashes on the steep outer slope of the old cone at the head of the Sèche until the resulting fluid mass slid off from the comparatively hard surface beneath and poured down the gorge of the river. There was plenty of water-soaked mud and ashes on the upper part of the mountain to supply the avalanche and some of it was on the verge of fluidity at the time of our visit, hence the latter explanation seems the more reasonable. The little tributary of the Sèche which empties into it on the southeast side close to our point of observation, did not show any corresponding torrent, because it does not head on the side of the great cone.

The mud-flows which have descended the Prêcheur River canyon have had ample collecting ground in the "Atrio de caballo," to use a Vesuvian term, on the north and northeast sides of the great crater, where the fine dust settles in vast quantities ready, when sufficient water has been added to it, to descend through a narrow gorge into the valley of the Prêcheur. When I was walking along the crater rim above the "Atrio" June 20, my footsteps started small mud-flows down the outer cone, so liquid was the mud at that time. The ordinary action of the volcano is to deposit dust of impalpable fineness on the inner face of the crater rim. When this deposit becomes thick, it is ready to be swept off by a copious rain and carried through the great southwestern gash, out of the crater and down the gorge of the Rivière Blanche as a mud-torrent or flow. There does not seem to the writer to be any need of locating "mud craters" at the heads of or along the line of the gorges which have been the courses which these torrents of liquid mud have followed to the sea.

Where the tuff agglomerate of the old (outer) cone had been freed from its coat of ashes, especially in its lower portion, i.e., from 1,000 to 2,000 feet above tide, it showed a smooth, somewhat fluted surface, the soft bowlders having been planed off even with the matrix. The whole showed striations parallel with the slope so that the surface looked like the glaciated rock surfaces so common in northern latitudes. The planing and the striations seem to have been due to the scouring action of the ash avalanches in this part of their course. They ceased where the steep slope of the cone changed to the gentle slope of the plateau, and thus gave opportunity for the material of the avalanches to check its descent and pile up. The sides of the radial gorges on the flanks of Mt. Pelée show approximately horizontal striations. Near the stream-beds such striations occur on both sides of the gorges, and are due to abrasion by the sand and stones carried by the torrents. High above the stream on the bluffs facing the crater there are similar striations, but these must have been made by sand-blast action during the hurricanes of dust-laden steam, resulting from the explosions during the recent great eruptions. These striations extend to the very tops of bluffs rising 500 feet and more above the stream beds at their bases.

Erosion seems not yet to have cut deeply into the old land-surface since or as a feature of the eruptions, because here and there all over the mountain side one can find undisturbed roots and charred grass still in place. The shore line from Ste. Marthe Point nearly to Cape St. Martin has been somewhat altered since the eruptions began, some of the river deltas having been built out by the new material brought down by stream and torrent, while others have been cut back by the waves. The most important example of the cutting back is near the mouths of the Sèche and the Blanche, where local land-slides have assisted the sea in forming nearly vertical bluffs from ten to thirty feet in height. These bluffs show sections of the old and the new material now composing the plain. The little ash island which was formed near the mouth of the Rivière la Mare between May 8 and 23, and which was visited on May 23 by Mr. Curtis and two companions, had been washed away by June 14. The stone pavement laid on the beach of St. Pierre was cut into in places, perhaps by the return waves from the ocean accompanying the great outbursts.

The mud-flow which swept down the Grande Rivière reached the village of the same name at 4 a.m., May 8, four hours before the eruption occurred which destroyed St. Pierre. Three other great mud-flows have traversed this river: on May 11, June 6 and June 22, though no great eruption of Pelée took place on May 11 or June 22. The eruption of June 6 was one of the heaviest that occurred; this time the mud-torrent reached Grande Rivière village about an hour and a half before the eruption took place. The flood of May 8 was the most violent and was three meters (about 10 feet) deep where the valley of the river opens onto the sea coast, according to M. Delsol Désiré, the mayor's deputy of Grande Rivière. He gave me the foregoing particulars in regard to these floods. The fine mud of these flows entered the buildings on the banks of the river as if it had been thick syrup. In one room that we examined the line of highest level was even with the top of an ordinary table, which would show that the mud was 30 inches deep in the room. At the time of our visit the deposit was nearly dry and it showed a shrinkage of but eight inches or 27 per cent. In another room the shrinkage was greater, showing that the mud there was thinner when it flowed in. Streams composed of such material as this would have great power in the transportation of bowlders. . . . Some of those measured were eight feet across. The bowlders seem to be from old deposits, since they have weathered surfaces. They show fresh abrasion along edges and at corners, due to their recent trip down the gorge. The mud is made up of gray material from the present eruption, together with a large proportion of yellow sand from the old beds through which the river runs. The vast amount of material brought down by the torrents has extended the delta plain fully five hundred feet into the sea and has pushed out the shore-line for several hundred yards on either side of the mouth of the river.

At Basse Pointe the history in regard to floods or torrents of mud has been similar. The principal disasters occurred on May 8 and 27, but the latter was the greater and most of the destruction was wrought on that occasion. Here too the deltal plain has encroached five hundred or six hundred feet on the sea and the ocean currents have spread the surplus material as a new beach for a long distance north and south of the mouth of the river, destroying the little artificial harbor of the town. Bowlders ten feet across were brought down and left in the town by the floods, and a deposit of sand, gravel and bowlders fifteen to eighteen feet deep rests upon the site of the old market place, which was at the mouth of the river.

The ruins of the city of St. Pierre presented a very interesting field of study, but mostly in the line of speculations as to the cause or causes of the terrible destruction of human life. The walls of the houses showed that one or more blasts of tornadic violence had swept over the city and that they came from the direction of the crater of Pelée, for the east and west walls —transverse to the direction of the crater from the city—were demolished more generally than the north and south walls. The direction in which most of the trees were felled indicates the same thing, but the trees in the angle of Morne Mirail, which rises behind the middle of the city, were thrown over at all angles progressively, showing that a vortex was formed there. As is indicated by the gradually decreasing degree of destruction in passing from the northern to the southern part of the city, the blast diminished in force as it progressed and expanded, but when it reached Ste. Marthe Point it still had strength enough to throw the statue of Notre Dame de la Garde from its pedestal. The statue, which is of hollow iron ten or eleven feet high, now lies on the edge of the bluff with its foot about fifty feet S. 10° W. from its original position on the pedestal, and directly in line with the crater. The guns in the Ste. Marthe and Morne d'Orange batteries were thrown from their carriages in the same direction. More than once when I was on the rim of the crater or on the west flanks of the mountain I saw great clouds of dust-laden steam come out of the gash in the side of the crater with sufficient force to descend the gorge of the Rivière Blanche with great rapidity a full mile before rising in columns. It was not difficult to imagine that, if this happened when the crater was sending a steam and dust column only one or two thousand feet high, the action would be vastly greater and even like a hurricane in violence when the crater was in full eruption and was sending its ash-laden steam column from five to seven miles into the air.

It does not seem necessary to call in any forces new or strange to the history of vulcanism to account for the phenomena attending the eruption of Mt. Pelée, or the destruction of St. Pierre and its people. The "flames" reported were perhaps the incandescent stones and bombs flying through the air; and these certainly would set fire to any combustible material upon which they fell. The officers of the French cable-repair ship *Pouyer Quertier* were eye-witnesses of the eruption of May 8 and describe the cloud as being black when it issued from the crater, but say that it became luminous as it approached the coast. Several times at night during our stay we saw the inner cone of the crater outlined and streaked with lines of "fire" due to the rolling and sliding, red-hot rocks and lapilli, and this light was reflected from the steam clouds above the cone. The existence of notable quantities of burning or inflammable gases in the discharges from the volcano seems to me to be as yet undemonstrated.

Eruption of Katmai

One of the greatest eruptions in recent times was that of the volcano Katmai, Alaska, in 1912. However, since the surrounding region is only sparsely inhabited the event did not at once attract the general attention it deserved. Several years after the eruption, expeditions sent by the National Geographic Society found and studied a great field of fumaroles, known as "The Valley of Ten Thousand Smokes," which was left as a relic of the volcanic activity. These expeditions also gathered a large amount of information about the 1912 eruption, by studying its visible effects and by questioning people who passed through the ordeal; and a vivid account was written by Robert F. Griggs, in his book *The Valley of Ten Thousand Smokes* (1922).

Imagine yourself in a pioneer village of about 300 people at an out-of-the-way place on the coast of Alaska. Everything is peaceful, the sky is clear, and a U. S. revenue cutter, coaling at the little dock, excites the little community by the faint but unaccustomed touch it gives with civilization. It is June, and therefore nearly 24 hours of daylight are to be expected at that far-north latitude.

In the afternoon a strange dark cloud approaches gradually from the northwest. This in itself attracts only casual attention. But at five o'clock, with the cloud overhead, a remarkable light-colored powder begins to fall. It is not snow, for it is not cold. In fact the substance resembles nothing so much as dry, powdery ash. At first the fall is light. People are fascinated, and hasten to collect samples of this wonderful "dry rain" as mementoes. Gradually the ash thickens in the air, until the light grows dim and finally gives way to total darkness.

In this way the people of Kodiak began their terrifying experience of June, 1912. During the whole night the silent, suffocating dust settled down. It was so fine that it penetrated into the tightest rooms. Toward morning the fall began to slacken, and about nine o'clock it stopped. The people sighed with relief, for the deadly peril seemed past; but awkward difficulties

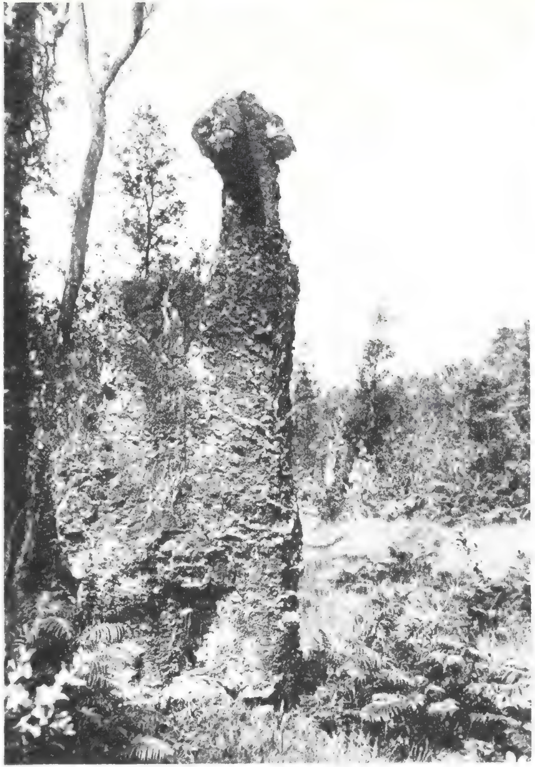


Photo Kanemori

A. "LAVA TREE"

A hollow shell of basalt formed around a tree. The tree burned, and the body of lava moved on.

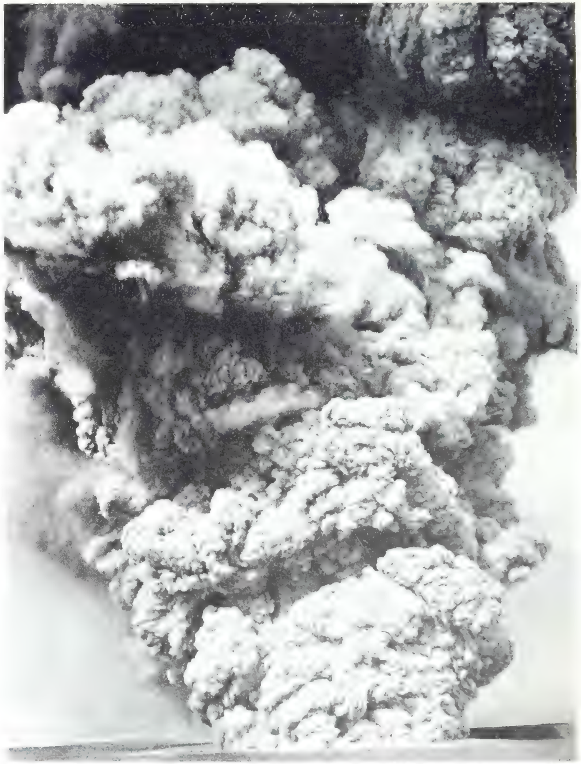
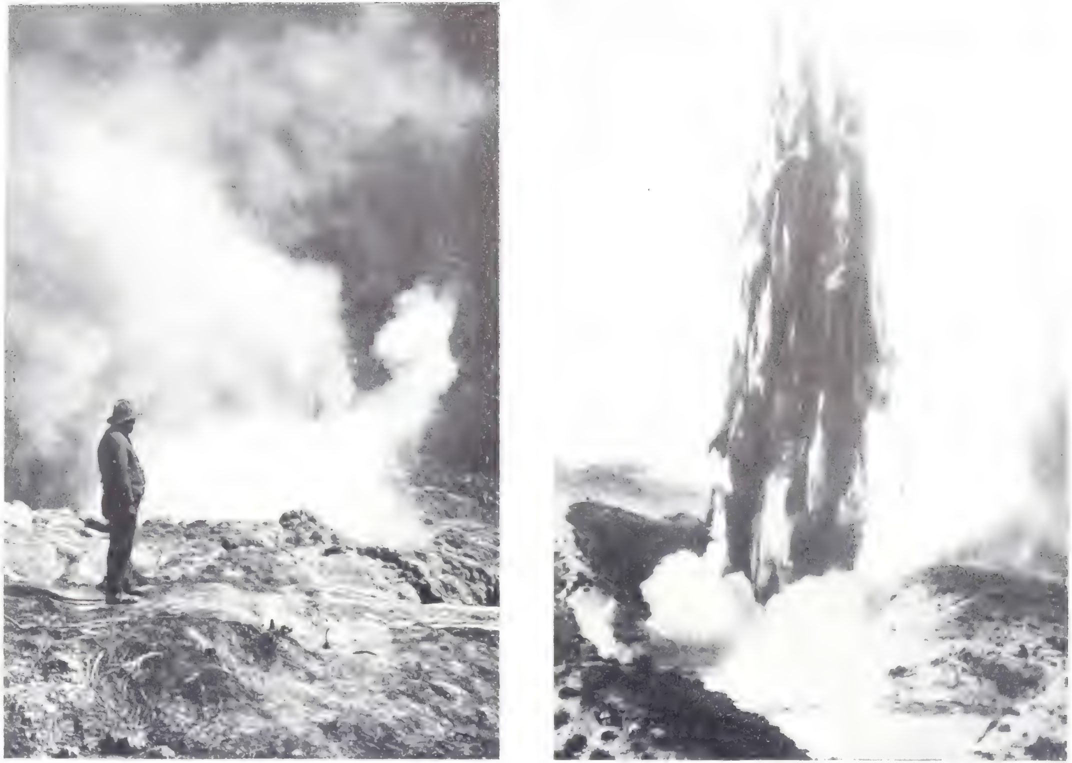


Photo Tai Sing Loo

B. CAULIFLOWER CLOUD

Explosive eruption of Kilauea, Hawaii, May 22, 1924.

PLATE XXXI



New Zealand Government Publicity Photo

A. WAIRAKEI GEYSER

New Zealand Government Publicity Photo

B. WAIMANGU GEYSER

Signs of decadent volcanism in New Zealand.

remained. Everything was covered with five inches of the fine, gritty ash, and as all the wells were choked with the material there was no water for drinking. The revenue cutter was a godsend in this emergency because with its evaporators it was able to purify enough sea water to supply the village.

At noon of the same day, to the consternation of all concerned, the falling of ash started again; and within two hours the darkness of night returned. Genuine terror now took possession of the community. Some had heard of ancient cities buried by ash, and they began to fear the same lot for Kodiak. The revenue cutter was having its troubles also. Despite frequent use of the fire apparatus it was almost impossible to keep the decks free from the persistent accumulation. Of course the vessel could have raised anchor at the first lull in the fall, and run away from the menace; but that would have left the threatened village without any help.

The captain communicated with the townspeople, and it was arranged that all should come aboard as soon as the ash slackened enough to permit safe navigation. During the night there were lurid flashes of lightning and loud peals of thunder, although nothing fell except the ash. This kept up until the following afternoon, when the air cleared sufficiently to reveal a brownish world; for the material of the second fall was a bright terra cotta, in contrast with the gray hue of the first.

The people lost no time in getting aboard, and the cutter dropped down the bay, stopping at an island to get 100 additional people. This made a total of 500, although the vessel was equipped to carry not more than 100 in comfort. With this crowd occupying every available foot of space, ash began falling again that night. The misery of the people under these conditions was extreme; but at least they had passed the inlet before the new darkness came, and could steam away without great danger if conditions did not improve. On the following day, however, the sky cleared. The people clamored to be taken back to their homes, to escape the immediate agony of living on the small vessel, and the captain complied. This time their optimism was justified, for no more ash fell. The three layers, distinguished readily on the basis of color, remain as a reminder of the brief reign of terror.

It should be kept in mind that Kodiak is more than 100 miles from the volcano Katmai; so far that the population had no indication of the mighty eruption until the ash reached them. This fact permits some conception of the great radius within which direct effects of the catastrophe were felt. Of course the ash fell into all the surrounding sea, making a deposit similar to numerous solidified ash beds that are found in ancient marine strata. On the leeward side, the extreme reach of the fine dust was many hundreds of miles. And even to windward there were more subtle, though equally disagreeable, results of the explosion.

For countless ages volcanoes have been transferring gases from the interior of the Earth to the atmosphere. Some of these gaseous products form chemical combinations, and the resulting substances find their way into the soil, or, as soluble salts, into the ocean; but probably some of the gases derived from volcanoes remain permanently as constituents of the air. The sum total of material thus derived from the interior of the globe must be enormous. Even during a single eruption the gases may be distributed to astonishingly great distances. Vancouver, British Columbia, fully 1,500 miles away, experienced slight effects from the Katmai eruption. Evidence of the most noticeable gases liberated on that occasion is discussed in the following despatches.

Seward, Alaska, June 11, 1912 [Seward is 250 miles northeast of Katmai]: A slight rain fell at Seward to-day. The water was charged with sulphuric acid, which is killing all vegetation and eating into the metal work of buildings.

Cordova [360 miles northeast], June 11: The first real danger here was made apparent when a heavy rain began to fall. The water mixing with the ash in the air formed sulphuric acid which burned painfully whenever it came in contact with the unprotected parts of the bodies of persons in the street. Before the cause was realized many persons received painful burns in the eyes, although none were severely injured.

Vancouver, B. C., June 12: Scores of housewives in Vancouver were sufferers because acid, presumably from the Alaskan eruptions, permeated their fine white clothes hanging on the lines after the Monday washing. Linen goods were apparently the only ones attacked. When this white wear came to be ironed it simply fell to pieces, and not until many complaints had reached dry goods houses to-day were the women able to solve the problem.

Volcanology

Intensive studies of a volcano during and immediately after great eruptions have great value, but scientists recognize that the most significant secrets of volcanism can be learned only by continuous observations and records extending over a long period of years. Accordingly large and well-equipped observatories are being established in volcanic regions. Specialists in volcano lore, known as *volcanologists,* live at these observatories and make a detailed record, from day to day, of every incident that may be connected with volcanic activity. A station of this kind has been maintained on the flank of Vesuvius for many years. Scientists in charge submit to numerous unpleasant experiences and sometimes risk their lives in order to get complete information. During the eruption of 1906 a thick layer of ash fell on the observatory, and on more than one occasion it appeared that the disaster of 79 A.D. might be repeated.

Another volcano observatory was established about 20 years ago near the rim of the great crater pit of Kilauea, Hawaii. Every incident in the behavior of this volcano has been observed and recorded since the station began operation. Delicate seismographs mounted at the observatory record every tremor and tilt of the ground caused by the surging of molten rock beneath the surface. Halemaumau, the present active vent in the floor of the crater, has served as a laboratory to the volcanologists, who have analyzed the lava and its gases, measured the temperatures at various depths, and made other valuable determinations. From analysis of all the data collected, some of the laws that control the volcanic processes are beginning to be understood. It is clear that the activity follows a fairly definite cycle, rising to crescendos and sinking again to comparative quiescence in a fairly regular period of years. This knowledge makes it possible to predict the behavior of Kilauea with reasonable assurance.

At an early stage in the intensive study of Kilauea it became evident that this volcano is related in its activities to Mauna Loa, whose crater is at an elevation 10,000 feet higher. Many years earlier James D. Dana, with only scattered observations to guide him, decided that the two vents were entirely independent. The present view is expressed in the following paragraph (Jaggar, 1912, pp. 3, 4):

> From what we see to-day, in accounting for the birth of distinct volcanoes, there seems to be no argument against a succession of vents, for a single area and for the same lava column. That is to say, the upward pressing lava of Hawaii, occasionally bursting forth in a Mauna Loa flow, and partly shown in the pit of Kilauea, is the same spouting stream that spread far and wide to lay the foundation ages ago for the sugar lands of Hamakau on the slopes of Mauna Kea. We can think of that stream as W. Lowthian Green saw it, squeezed up through the great Hawaiian rift or rifts which for millennia have fed the Hawaiian ridge. The cause of the steady upflow may be a subsiding of the ocean's bottom all about, or it may be the elastic force contained within the liquid itself or its imprisoned gases. Whatever the cause, and however much greater the total activity may have been in the past, there is no reasonable doubt that the lava column shifts its outlets in the ridge as a whole, just as the lava of individual volcanoes breaks out in new places to make lateral flows. Mauna Loa at some time began its existence as a new crater, just as did Matavanu in Savaii in 1905 in the Samoan archipelago. The lava column so released was the ancient writhing and rising slag, which again and again had broken its bounds and made the Samoan land. So with Kilauea and Mauna Loa; we can think of them as piled above cracks on the border of Mauna Kea, whither the ancient pushing lava column migrated when it found the height and mass of Kea too great for any further central outbursts. The process may be compared to that which forms little leaf-like sand deltas after a heavy shower. The roadside rills build a lobe, become stagnant, shift to a new position at one side, and build again. The lava column builds thus in a circle about an upright tube of its own maintenance, its

source below being a rift. It constructs the circular cone to a size commensurate with its own volume and power. When the cone is so great that it dams back the lava, it is expectable that the latter will find it easier to escape elsewhere along the deep subterranean rift, or to make a new crack for itself.

In 1924 Kilauea became violently active, and after a genuinely explosive eruption lapsed into unusual quiet. The violence of the last outburst was a surprise to many students of volcanism, since the Hawaiian volcanoes ordinarily produce only quiet lava flows. For more than a month preceding the unusual eruption the vicinity of Kilauea was disturbed by numerous earthquakes, some of them quite severe. The following extracts (Jaggar and Finch, 1924, pp. 358, 365, 366, 372) from a journal kept at the observatory record the progress of the explosive activity:

May 13, 1924.

Kilauea volcano entered upon an explosive phase, with broken rocks thrown out from Halemaumau pit, during the early morning of May 11, and the like of this has been unknown here since about 1790. . . .

On Tuesday, May 13, 1924, the explosions became more frequent, five being observed during the day. One rock weighing about 400 pounds was hurled 200 feet from the pit. The explosion at 4 p.m. May 13 sent up rocks 2,500 feet in the air. One of these stones weighing 300 pounds landed in the roadway 1,400 feet from rim of pit, and another weighing 100 pounds fell near the road 1,800 feet from the pit.

The rocks of each explosion were largely confined to one sector of the ground encircling Halemaumau, but by May 14 nearly all sectors were covered.

During the first few days of this eruption, the clouds above the pit were largely charged with dust from avalanches. Hundreds of tons of dust have been deposited around Halemaumau and in the Kau Desert.

The rim of the pit has been greatly changed owing to large segments falling in at the south and southwest, including the long fault bench there.

Numerous earthquakes have been felt at the Observatory, though more of them are perceptible at Uwekahuna bluff.

On May 13 the amount of fumes greatly increased and during the afternoon of May 14, prior to an explosion at 3:37 p.m., there was a continuous moaning roar like the noise heard at the source fountains of the Alika flow in 1919.

May 20, 1924.

The explosive eruption of Kilauea continued during the week, reaching a maximum May 18. On that day one man who ventured too near the pit was killed. His leg was crushed by a barrage of ejected stones, and he died on the following day from the effects.

The surf-like, roaring noise preceded explosions and diminished after them. Excessive tremor was recorded during the first few days only. Earthquakes were numerous. Heavy electrical storms accompanied by pisolitic mud rains followed the larger explosions. Brilliant lightnings shot through the cauliflower ash clouds. A marked air concussion was felt before the larger explosions.

Seismographic records of the explosion earthquakings are peculiar in that many of them, instead of starting suddenly as in ordinary local earthquakes, wax gradually to a maximum and die away in the same fashion.

Avalanches continually enlarged the pit. May 15 there was an avalanche from Uwekahuna cliff, and yellowish cascades of mud followed occasionally by a cloudburst.

The last conspicuous explosion throwing rocks began at 9:14 a.m. May 24. The rock trajectories made tails of vapor or dust to a height estimated at 3,000 feet. The dust cloud was over 6,000 feet high. There were lightnings in the middle of the dense black cloud, and short cracks of thunder were heard. There were four or five major explosions in this eruption, the ground trembled, and a heavy deposit of ash was added to the country immediately north and south of the pit. By 9:35 a.m. the eruption was over.

June 3, 1924.

After the explosive eruption there were numerous small quakings at the Kilauea rim, recorded during the week to the number of from twenty to sixty per day by the instruments, the numbers decreasing. Some of these were felt as moderate earthquakes to the number of three or four per day, but most of those felt merely rattled doors or windows, perceptibly only at night. Some earthquakes of this period were felt generally over the island of Hawaii.

The pit had now become a large cauldron of oval shape floored with broken rocks, its longest diameter 3,400 feet, its width 3,000 feet and its depth about 1,330 feet.

The walls showed horizontally bedded lavas in the upper sections and large platy intrusive bodies of whitish aspect near the bottom, especially north and north-west. The lower walls exhibit dykes or fissure fillings of lava, twelve or fifteen of these being in evidence below petering out upward so that only two are to be detected in the upper wall. The two dyke exposures rising through the upper beds appear to be the same fissure on opposite sides of the pit, and that is the southwest rift of 1920. Along its course up and down the southwest wall this dyke in two places becomes a cavern leading away underground toward the 1920 flows in the desert. In the upper hundred feet even this dyke thins out to nothing.

The bottom area was steaming vigorously and from the rock walls avalanches fell frequently. Some purring noise could be heard from gas vents in the bottom. A flat area of the bottom appeared to be partly mud. Much of the débris slope was wet.

Thus Kilauea, by its unexpected behavior, demonstrated that even the basaltic volcanoes may have violent moods. Under certain conditions the gases, which ordinarily escape with ease from the fluid basalt, are repressed until they burst forth in fury.

For many years previous to 1924 the fiery lake of Halemaumau was an awesome sight to which visitors were attracted in large numbers. The present comparative tameness of the famous volcano represents only a temporary lull, as explained by one of the volcanologists (Wilson, 1927).

Among the questions now most frequently asked by visitors at Kilauea are: "Is the volcano dead?" and "When will the next eruption be?" The Volcano of Kilauea is not dead. The second question is not so easily disposed of, as the principles involved in trying to answer it are most complicated and intricate. To be able to predict earthquakes and volcanic eruptions has long been the aim of seismology and volcanology (see "Predicting Earthquakes," by T. A. Jaggar, in *Scribner's Magazine*, October, 1924). The lines of reasoning that have seemed most often to hit the mark are, first, to learn through local history the habits of the area in question, and second, to observe and correlate current symptoms and phenomena. The earth's forces slowly accumulate stresses that are deep beneath the surface, of which the indications are difficult to observe. Periodicity is a good hand-hold for prediction, particularly in dealing with volcanic eruptions. . . .

The history of Kilauea reveals other quiet periods like the present one. Old residents here remember the relatively dormant period between 1894 and 1907, when people were asking then, just as they are now, "Is the volcano dead?" Could they have then foreseen the high lava activity of 1920, and the explosions of 1924, the question would have seemed ridiculous. The present quiet phase is but part of the cycle of the volcano; history repeating itself. As time goes on, a longer recorded history will be available for the study of periodicity; the symptoms of accumulative and accidental effects will become better understood; causes will be recognized, and forecasting will rest on a firmer foundation.

BIBLIOGRAPHY

Chapter IX—Volcanoes and Volcanism

T. Anderson and J. S. Flett, *Report on the Eruptions of the Soufrière, in St. Vincent, in 1902, and on a visit to Montagne Pelée,* *in Martinique.* Philosophical Transactions of the Royal Society of London, Series A, vol. 200, 1903, pp. 378, 380-381, 392-396, 447-448, 450, 452-453, 481-483, 499-500, 523.

Arnaldo Cortesi, *Report on Eruption of Mount Etna.* New York *Times,* Nov. 6, 8, 9, 1928.

Daniel C. Gilman, *Life of James Dwight Dana.* New York: Harper and Brothers, 1899, pp. 124-125.

Robert F. Griggs, *The Valley of Ten Thousand Smokes.* Washington: National Geographic Society, 1922.

E. Otis Hovey, *Observations on the Eruptions of 1902 of La Soufrière, St. Vincent, and Mt. Pelée, Martinique.* American Journal of Science, vol. 14, 1902, pp. 323-328, 342-349.

Thomas A. Jaggar, *The Cross of Hawaii.* Honolulu Chamber of Commerce, 1912, pp. 3-4. *Volcano-glacier Floods.* The Volcano Letter, Volcano House, Jan. 25, 1928.

Thomas A. Jaggar, and R. H. Finch, *The Explosive Eruption of Kilauea in Hawaii.* American Journal of Science, vol. 8, 1924, pp. 358, 365, 366, 372.

Sir Charles Lyell, *Principles of Geology.* Ninth Ed., New York: Appleton, 1860, pp. 363-374, 389-393, 411-412, 425-427.

R. M. Wilson, *Cyclical Volcanic Activity.* The Volcano Letter, No. 131, Volcano House. June 29, 1927.

CHAPTER X

MOVEMENTS OF THE EARTH'S CRUST

For generations prior to the year 1886 the people in and near Charleston, South Carolina, had a natural faith in *terra firma*. Their experience had encouraged a confidence that the solid bedrock beneath them was immovable and safe. But without warning the foundations of the city rocked with destructive violence, and the old confidence was rudely destroyed. Similar catastrophes in other "stable" lands adjoining the Atlantic Ocean have served to convince us that no part of the Earth's crust is immune to disturbance, and that no land can be entirely free from earthquakes.

A major earthquake results from an abrupt adjustment in the Earth's rocky shell. The trembling of the Earth from such a blow can be analyzed in detail by means of precise instrumental records. But after all, the greatest fascination of earthquake study lies in the effect of violent shocks on man and his affairs. Fortunately a number of excellent eye-witness accounts of the Charleston disaster have been preserved. The following extracts from one of them (Dutton, 1888, pp. 212-219) are typical:

While engaged in his usual duties on the second floor of The News and Courier building at the time of the first shock, the writer's attention was vaguely attracted by a sound that seemed to come from the office below, and was supposed for a moment to be caused by the rapid rolling of a heavy body, as an iron safe or a heavily laden truck, over the floor. Accompanying the sound there was a perceptible tremor of the building, not more marked, however, than would be caused by the passage of a car or dray along the street. For perhaps two or three seconds the occurrence excited no surprise or comment. Then by swift degrees, or all at once—it is difficult to say which—the sound deepened in volume, the tremor became more decided, the ear caught the rattle of window-sashes, gas-fixtures, and other movable objects; the men in the office, with perhaps a simultaneous flash of recollection of the disturbance of the Friday before at Summerville, glanced hurriedly at each other and sprang to their feet with the startled question and answer, "What is that?" "An earthquake!" And then all was bewilderment and confusion.

The long roll deepened and spread into an awful roar, that seemed to pervade at once the troubled earth and the still air above and around. The tremor was now a rude, rapid quiver, that agitated the whole lofty, strong-walled building as though it were being shaken—shaken by the hand of an immeasurable power, with intent to tear its joints asunder and scatter its stones and bricks abroad, as a tree casts its over-ripened fruit before the breath of the gale.

There was no intermission in the vibration of the mighty subterranean engine. From the first to the last it was a continuous jar, adding force with every moment, and, as it approached and reached the climax of its manifestation, it seemed for a few terrible seconds that no work of human hands could possibly survive the shocks. The floors were heaving underfoot, the surrounding walls and partitions visibly swayed to and fro, the crash of falling masses of stone and mortar was heard overhead and without, the terrible roar filled the ears and seemed to fill the mind and heart, dazing perception, arresting thought, and for a few panting breaths, or while you held your breath in dreadful anticipation of immediate and cruel death, you felt that life was already past and waited for the end, as the victim with his head on the block awaits the fall of the uplifted ax.

For a second or two it seemed that the worst had passed, and that the violent motion was subsiding. It increased again and became as severe as before. None expected to escape. A sudden rush was simultaneously made to endeavor to attain the open air and fly to a place of safety; but, before the door was reached all stopped short, as by a common impulse, feeling that hope was vain—that it was only a question of death within the building or without, of being buried beneath the sinking roof or crushed by the falling walls. The uproar slowly died away in seeming distance. The earth was still, and, oh! the blessed relief of that stillness!

But how rudely the silence was broken! As we dashed down the stairway and out into the street, from every quarter arose the shrieks, the cries of pain and fear, the prayers and wailings of terrified women and children, commingled with the hoarse shouts of excited men. The air was everywhere filled to the height of the houses with a whitish cloud of dry, stifling dust, arising from the lime and mortar of the shattered masonry, which, falling upon the pavement and stone roadway, had been reduced to powder. Through this cloud, dense as a fog, the gas-jets flickered feebly, shedding but little light, so that one stumbled at every step over the piles of bricks, or became entangled in the telegraph wires that depended in every direction from their broken supports. On every side were hurrying forms of men and women, bareheaded, partially dressed, some almost nude, and all nearly crazed with fear and excitement. Here, a wife is supported, pale and fainting, in the arms of her husband. Her arms hang listlessly by her side, her head has fallen backward on his shoulder; he bears her past, whispering words of encouragement in answer to her low and repeated moans, and they are lost in the mist. A few steps away, under the gas-lamps, a woman lies prone and motionless on the pavement, with upturned face and outstretched limbs, and the crowd which has now gathered in the street passes her by, none pausing to see whether she is alive or dead. A man in his shirt sleeves, with blood streaming over his clothing from a wound on his head, moves about among the throng without being questioned or greeted; no one knows which way to turn, or where to offer aid; many voices are speaking at once, but few heed what is said; you take note of all these things as one in a dream. The reality seems strangely unreal; and through it all is felt instinctively the presence of continuing, imminent danger, which will not allow you to collect your thoughts or do aught but turn from one new object to another.

A sudden light flares through a window overlooking the street. It becomes momentarily brighter, and a cry of "Fire!" resounds from the multitude. A rush is made towards the spot; a man is seen lying doubled up, silent and helpless, against the wall; but at this moment, somewhere—out at sea—overhead—deep in the ground—is heard again the low ominous roll which is already too well known to be mistaken. It grows louder and nearer, like the growl of a wild beast swiftly approaching its prey, and all is forgotten in the frenzied rush for the open space, where alone there is hope of security, faint though it be. The tall buildings on either hand blot out the skies and the stars, and seem to overhang every foot of the ground between them. Shattered cornices and copings, the tops of the frowning walls, lie piled from both sides to the center of the street. It seems that a touch now would send the broken masses left standing down upon the people below, who look up to them and shrink together as the tremor of the earthquake passes under them, and the mysterious reverberations swell and roll along like some infernal drum-beat summoning them to die. It passes away, and once more is experienced the blessed feeling of deliverance from impending calamity, which, it may well be believed, evokes a mute but earnest offering of mingled prayer and thanksgiving from every heart in the throng.

Again, far along the street, and up from the alleys that lead into it on either side, is heard the chorus of wails and shrieks, shouts and prayers, which, though it had not ceased, was scarcely noticed a moment before. It is a dreadful sound; the sound of helpless, terror-stricken humanity, old and young, the strong and the feeble alike where all are so feeble, calling for help from their fellow-creatures, and raising their voices in anguished petition to Heaven for mercy, when no human aid could avail.

It is not a scene to be described by any mortal tongue or pen. It is not a scene to be forgotten, when once it has been witnessed, and when the witness has shared all its danger and felt all its agony.

The first shock occurred at about 9:51 o'clock, as indicated by the public clocks, the hands on all of which stopped at that fateful point, as if to mark the end of time for so many who had counted the recording strokes of the preceding hour without a thought but of long and happy life. The second shock, which was but a faint and brief echo of the first, occurred eight minutes later.

Soon after it had passed the writer started homeward, to find the scenes enacted on Broad Street around The News and Courier office repeated at every step. St. Michael's steeple towered high and white through the gloom, seemingly uninjured. The station-house, a massive brick building across the street, had lost its parapet and the roof of the portico, which had fallen in a mass—killing a woman, whose body then lay under the wreck. A little farther on the portico of Hibernian Hall, a handsome building in the Grecian style, had crashed to the ground, carrying down the massive pillars with it. All the way up Meeting Street, which, in respect of its general direction and relative importance, corresponds with Broadway in New York, the ground was piled with débris from the tops of the walls on either side. In passing the Charleston Hotel, which, to carry out the comparison above indicated, occupies the position of Stewart's uptown store [1] in New York, the third shock was felt about ten minutes after the second, and of course caused the greatest alarm in that neighborhood, as elsewhere. At Marion Square, corresponding with Union Square, New York, a great crowd had already collected, as even the borders of the extensive plaza could not be reached by the nearest buildings in event of their fall, and the number of fugitives was momentarily increased by new arrivals pouring in from every side.

---

[1] Now Wanamaker's, at Ninth Street and Broadway.—Ed. Note.

From this crowd, composed of men, women, and children of both races, arose incessant calls and cries and lamentations, while over the motley, half-clad assembly was shed the lurid light of the conflagration that had broken out a hundred yards beyond the square immediately after the first shock, and now enveloped several buildings in flames. In three other quarters of the town, at the same time, similar large fires were observed under full headway; and the awful significance of the earthquake may be most fully appreciated, perhaps, when it is said that, with these fires blazing up at once around them, the people whom you met on the streets, or saw gathered together in groups in the open places, evidently did not give them a thought. No one watched the ruddy flames or the black pillars of cloud rising high into the still night air. All were too intent on listening for the dreaded recurrence of that horrible growl or groan of the power under the sea and under the land, or on watching for the next manifestation of the mysterious force, to give a thought to the more familiar terror, though it had threatened his own home and every house in the doomed city.

Arrived at his home, the writer found the same condition of affairs that prevailed elsewhere. Every house in the vicinity was deserted. Interrupted in their evening pursuits, or aroused from sleep by the shocks and the sound of the fearful ruin being effected above and around them, the alarmed inmates had rushed into the streets, and were huddled together, trembling and fearful, awaiting the end, whatever it might be. Invalids had been brought out on mattresses and deposited in the roadway, and, together with the aged and the infant, were cared for as tenderly as possible. No thought was given anywhere to treasures left behind in the effort to save the priceless treasure of life itself—suddenly become so precious in the eyes of all who were threatened to be bereft of it.

The presence of the dead and wounded who were conveyed to the parks and public squares, added greatly, of course, to the distress of the already dismayed refugees in those places.

The bodies of the victims were laid on the ground in the midst of the camps, the dead being covered from sight by shawls or sheets, while skilled hands ministered to the sufferers who were yet within the reach of human aid. The physicians and surgeons performed their duty throughout the night with heroic devotion, and many chapters would be required to tell the story of their labors alone as it should be told.

Exaggerated rumors as to the number of the killed spread throughout the city soon after the shock, causing needless pain to many who, though spared the sight of the scenes of suffering and death so near to them, yet feared for the safety of relatives and friends of whom no tidings could be heard.

The long, anxious watch between midnight and day was not less trying than the shock itself. The suspense was indescribably painful, and had no relief for a moment, save when it gave place to recognition of the approach and presence of renewed danger. That passed, the breathless vigil began again, and the moments seemed as hours and the hours as moments until the next dread visitor had come and gone. Four severe shocks occurred before midnight. Three others followed at about 2, 4, and 8:30 o'clock, a.m., and every shock after the first caused even more alarm, naturally, than the first itself.

The apprehension of further and perhaps greater ill was shared by every one, and was not relieved for an instant. The character and extent of the disturbing force were not known, nor was there any reason to believe that the hardest shock had been experienced. Whether the blow had come from the sea or from the land none could say. At any moment another might be felt that would rend the earth asunder, or burst the bounds that held the waiting ocean in check and drive its waters sweeping in an overwhelming wave over all the low-lying peninsula where so many thousands were collected together without hope of escape. Night and distance shut out all the world. No word could be heard from beyond the confines of the stricken city; no human hand could be stretched to save a single soul, whatever fate was impending. The

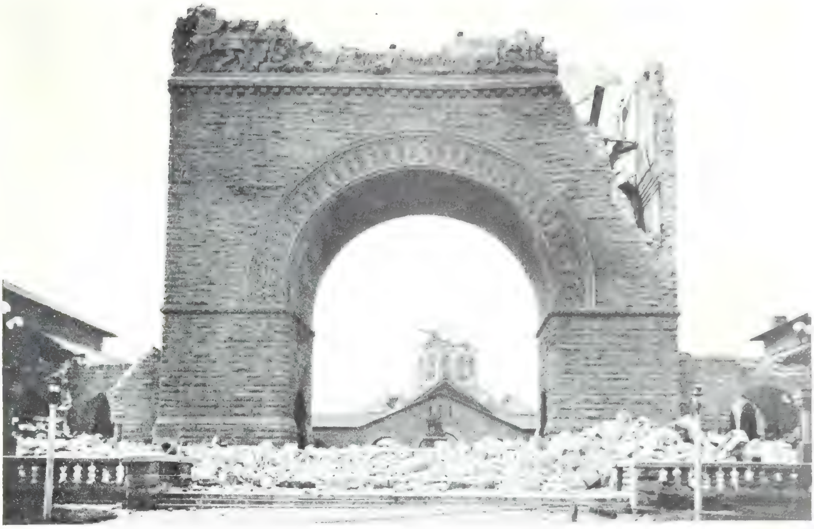


Photo W. C. Mendenhall

A. AFTER THE EARTHQUAKE

The great arch at Stanford University, California, after the earthquake of 1906.

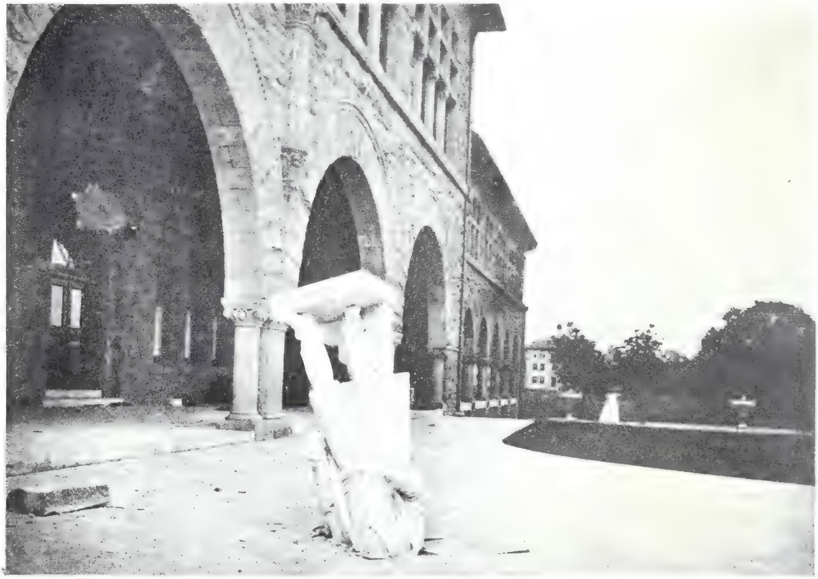


Photo W. C. Mendenhall

B. A HIGH DIVE

Statue of Louis Agassiz, thrown from the wall of a building during the earthquake of 1906. Stanford University, California.

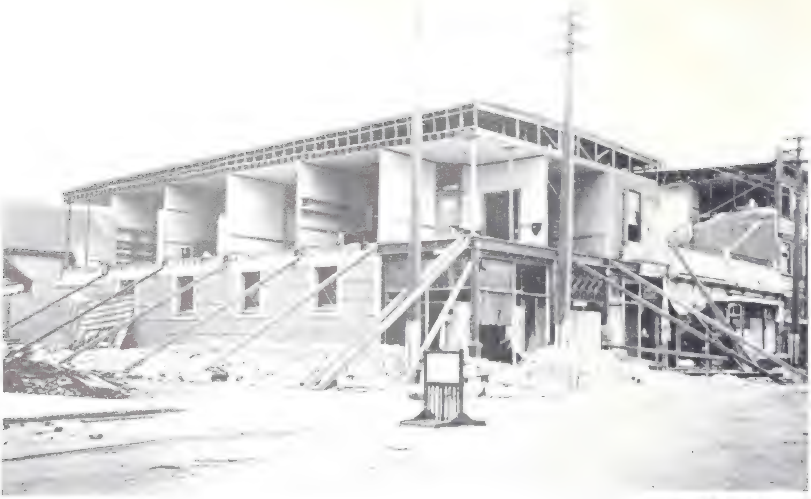


Photo W. C. Mendenhall

A. ONE OF A LARGE NUMBER

Walls of a house in Palo Alto, California, shaken down by the earthquake of 1906.

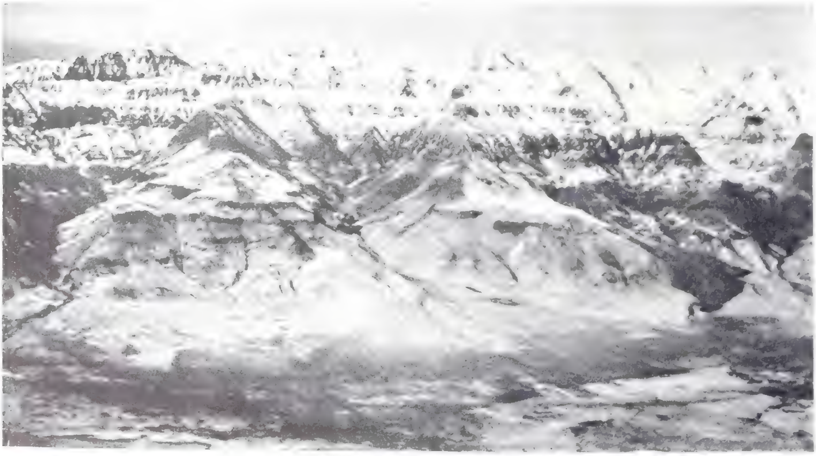


Photo R. E. Fuller

B. CAUSE OF MANY EARTHQUAKES

The front of Steens Mountain, Oregon, more than a mile high, made by faulting. Probably the movement was distributed over a long period, and each slip shook the Earth.

silence, save when broken by piteous cries, was oppressive in the extreme. In the late hours of the night even such cries would have been a relief to senses that were strained to so great tension to catch the first footstep of coming danger, the first low moan of the earth in the throes of convulsion. The air itself was strangely still. In the writer's garden an unprotected lamp burned until 4 o'clock, or later, with a flame that did not once waver. All nature seemed to be waiting in breathless suspense for the issue of the hour, of the next minute, the next moment. And then! always with startling suddenness, the great fearful Power rushed out of the darkness upon the city, shaking the ground with his tread, sending terror before him, and leaving trembling thousands panting in dismay as he passed. The impressions received at the time have doubtless become obscured by familiarity with the danger, and by the sense of comparative security that has since prevailed. The record of the night, none the less, is engraved too deeply in many hearts ever to be erased, and these will bear witness yet that this faint sketch enlarges no detail of the trials they endured that night for hours that seemed whole nights in themselves.

The rising sun on Wednesday morning looked on empty and broken homes and on streets encumbered with continuous lines or heaped masses of ruins, amidst which the wearied and shelterless citizens gathered together in little groups, or picked their way from place to place, wondering at the extent of the damage inflicted everywhere, and with renewed thankfulness in view of the perils escaped. No one was prepared for the scene that was presented by daylight. Every house was in worse condition than had been suspected. Some were utter wrecks, and many others were but little better off. For the first time the magnitude of the disaster began to be somewhat appreciated.

Those who flattered themselves that the morning had brought an end to their terrors and trials, however, and who timidly ventured to return within doors to commence the work of temporary repair or to provide for the wants of the day, were quickly undeceived. Another shock occurred about 8:30 o'clock, and caused the more excitement and apprehension because of the knowledge, that had now become general, of the dangerous condition of the buildings, and of the effects that might be expected to follow any further violent agitation. It had become known, too, that very many persons had been killed and wounded during the night, and that the ground had opened in numerous places in and around the city, the number and extent of the fissures being of course greatly exaggerated. Some alleged authoritative predictions of further violent shocks had also obtained circulation and credence. The latest shock, therefore, naturally caused widespread consternation. Another occurred about 1 p.m., another at 5 p.m., and another about 8 p.m. Those of the day fully determined all to avoid their houses until the disturbances had ended or appreciably moderated. Tents, awnings, and rude habitations of varied description were erected everywhere for such protection as they could afford. The entire population of the city was collected in the parks and streets, except a few families that had found refuge on the ships in the harbor. There was no lack of food, except that caused by the limited means for preparing it. The day was spent in improvising such necessary arrangements for camping out as the circumstances required and permitted.

The general aspect of the city is scarcely a subject for detailed description, and can more readily be conceived than put in words. It is enough to say that not more than a half dozen houses escaped injury, and that the damage to all would be represented by the demolition of one-fourth of the buildings on Charleston Neck; by the leveling of the houses south of Broad Street; or by the destruction of a city larger than Columbia. The ruins lay piled in the streets, yards, and gardens, and the houses from which they had fallen seemed ready to crumble of their own weight. Travel was confined to the middle of the streets and was impeded there. It is impossible to estimate, even approximately, the amount of masonry that was thrown into the streets; but it may be guessed at in some sort when it is said that the wreckage caused by the cyclone of the year before amounted to over ten thousand cart-loads, all of which was removed within the week following. The débris in a few streets after the earthquake would have equaled in mass all of a similar kind that was caused by the storm, and every street was obstructed more or less throughout its length. The work of removal was continued for months, and at the end of the year, and after, unsightly piles were still encountered in out of the way places, where they did not interfere with public or private convenience. There was enough, and more than enough, evidence of the ruin that had been wrought to oppress the most hopeful mind, and strangers visiting the city during the succeeding winter season were appalled by even the remaining signs of destruction which met their view. What it all meant to the people of Charleston on the morning of September 1, and the emotions to which it gave rise, can not be told. But the people were familiar with disaster, and one or two days later the writer saw a crowd of common laborers busily engaged in picking out and piling bricks from the wreck of the fallen wall of a building while the standing walls beside them were being shaken almost hourly by the recurring tremors.

Regular waves traversing the surface of the ground are reported very commonly in connection with great earthquakes. These visible waves affect only the loose soil, and are especially large on the surface of deep alluvium that is saturated with water. Charleston is built on alluvial land adjacent to a low coast, and the surface waves during the earthquake were conspicuous. No doubt there is a tendency on the part of excited witnesses to exaggerate the height of such waves; but the fact that the motion is distinctly seen and felt indicates that the amplitude is considerable.

Reports from several citizens of Charleston are essentially in agreement on the subject of the waves (Dutton, 1888, pp. 240, 265-267):

On the night of August 31 I was seated in a basement room of my dwelling, the floor of which is about eighteen inches above the surrounding soil, engaged in a game of chess. A member of the household was seated at a west window of the same room, about twenty feet from me. He heard the rumbling sound of the approaching shock coming over the water, and, in alarm, he immediately left the room through a door at the opposite or east side; the two players, being so absorbed in the game that they had not heard the noise, still remained seated. At that moment the wave reached the house, and, its violence being unexpectedly great, the oil lamp on the table was immediately extinguished by myself, and all the occupants of the room ran out into an adjoining garden. There, at a safe distance from the dwelling, I stood facing northward towards the house, the movement not yet being over. I was obliged to spread my feet apart to avoid being upset by the waves passing under me. These were from three to four in number, and seemed to be about six inches high, but this estimate of height is probably excessive.

Upon examining next morning the spot where I had stood there were two fissures to be seen in the hard shell walk three-quarters of an inch wide and 18 inches apart, quite straight and parallel, and running in a direction about north and south, at right angles to the direction of the wave. In the garden beds other fissures were noticed somewhat wider, but none as straight as these. . . .

Some very important testimony as to the height and direction of the earth waves on the night of August 31 is given by Dr. F. L. Parker, a prominent physician of Charleston, who was on Tradd Street, between Greenhill and Logan streets, when the first shock occurred. Dr. Parker says:

"I had just reached a point on Tradd Street opposite Mr. Lewis F. Robertson's garden gate when I heard a roaring sound, apparently in the direction of James Island Cut, which was southwest of where I stood. I made up my mind that a cyclone was coming and instinctively turned toward the direction indicated, confidently expecting to see the air filled with the flying débris from James Island. Seeing that the sky was perfectly clear, I stood awaiting developments, when I heard another and louder roar coming from the northwest. I then began to feel the vibrations of the earth very distinctly, and realized that they were produced by an earthquake. From that instant the vibrations increased rapidly and the ground began to undulate like a sea. The street was well lighted, having three gas lamps within a distance of 200 feet, and I could see the earth waves as they passed as distinctly as I have a thousand times seen the waves roll along Sullivan's Island beach. The first wave came from the southwest, and as I attempted to make my way towards my house, about one hundred yards off, I was borne irresistibly across from the south side to the north side of the street. The waves seemed then to come from both the southwest and northwest and crossed the street diagonally, intersecting each other and lifting me up and letting me down as if I were standing on a chop sea.

"I could see perfectly and made careful observations, and I estimate that the waves were at least two feet in height. In order to make my way along the street I had to tack, so to speak, from one side to the other, frequently being compelled to stop and hold on to something to keep from being thrown down. My progress along the street was similar to that of a person in a rapidly moving railway car who tries to walk from one end of the car to the other. When I had reached a point in front of Dr. Fraser's residence I saw the high brick wall between his house and the house of Mr. Parker Ravenel reeling from west to east. . . . At this moment one of the chimneys of the house on the opposite side of the street came crashing down in front of me. The greatest violence of the shock was over before I reached my house."

Mr. A. M. Lee, who resides just opposite the point where Dr. Parker first heard the roar, states that he also distinctly heard the first roar come from the southwest, and a moment or two later heard another and louder roar coming apparently from the northwest.

The following extracts from notes made by him soon after the shock of August 31 have been kindly supplied by Mr. J. K. Blackman, of Charleston:

"I furnish with pleasure, at your request, the following notes of some striking incidents which came under my observation at the time of the great earthquake of August 31 and on the following afternoon. I have been very careful in the statement of facts, and have confined myself to particulars which I can personally vouch for.

"At the time of the shock I was standing in an upper room of my house, a frame dwelling, at 5 Logan Street. The night being oppressively warm and close, all the windows and doors of the house were wide open. Everything without was as still as death. The first intimation I had of the shock was the shaking of the mirror on a bureau which stood against the south wall of the room. I next felt the quick vertical movement of the house, and am satisfied that it was at least five or six seconds before I heard the roar and felt the house begin to rock violently—from northwest to southeast. I observed at the time, and also during subsequent shocks, that this rocking, swaying motion struck the northwest corner of the house first, and always succeeded the vertical vibration by a few seconds, the interval varying with the violence of the disturbance. After the first few seconds it was impossible to fix accurately the direction of the swaying motion. The house is 65 feet long, running due east and west, and as the wave seemed to strike the building on the western end, at an angle diverging to the north, a wrenching motion was produced, which caused the building to oscillate both northeast and southwest, as well as to assume a rotary motion, the resultant of the other two and conflicting motions. I had neither the means nor the inclination to make exact observations during the progress of the great shock, but from notes recorded the next day and during the week ensuing, when every incident was painfully impressed upon my mind, I have selected the following memoranda:

"I made some effort during the night to observe, if possible, the movement of the earth waves; but, as each successive shock came, I found my attention engaged by other matters, and it was not until 5 o'clock the next afternoon that I accomplished my object. The shock at 5 o'clock Wednesday afternoon was probably the most severe of those that succeeded the great shock during the month of September. I was standing at the corner of Tradd and Legaré streets when I heard the preliminary roar, and determined to make the desired observation at all hazards. Tradd Street is paved with Belgian blocks, and when the movement of the earth began I was standing in the center of the roadway. After the first vertical tremor had passed, and while I was being swayed to and fro by the succeeding horizontal movement, I distinctly saw four or five separate waves pass across Tradd Street. . . . As nearly as I can estimate the width of the several waves, they were about as wide as the roadway between the sidewalks; as to their height, I would not like to venture an estimate, but each seemed to be at least a foot high, and was certainly high enough to be plainly seen. Had Tradd Street been under water, and had I been standing in a boat on its surface, the motion communicated to my body by the passing swells could not have been more plainly felt, nor could the waves have been more plainly seen. The waves traveled at a very high rate of speed, and followed each other almost simultaneously. Although I experienced a very large number of shocks, the shock of Wednesday afternoon, September 1, was the only one during which I could distinctly see the waves of motion."

It is clear from the detailed evidence cited by witnesses that the center of the shock was to the west of Charleston, since the waves that affected the city moved eastward. The conviction expressed independently by several citizens that waves advanced both from the southwest and the northwest is justified by later scientific study of the earthquake area. There were indeed two distinct centers, several miles apart, from each of which the surface waves moved outward in much the same way that concentric ripples spread from the point at which a thrown pebble strikes the water in a pond. The direction of the impulse at various other towns in the region differed according to the location of the place with respect to one or the other of these centers. Summerville, which is slightly north of the northern center, was visited and studied carefully by a scientist shortly after the earthquake (Dutton, 1888, pp. 274-275):

> Mr. W. J. McGee, of the Geological Survey, who visited Summerville on September 3 and 4, says in his notes:
>
> "Perhaps three-fourths of the chimneys in the town have been displaced, and perhaps three-fourths of these have been thrown either to the north or south. Fissures were common and extensive and considerable streams of water flowed from them. In some fields in the vicinity of Summerville one-quarter of the surface has been flooded by water and is covered by films of yellow or blue sand; and in some cases long lines of little hillocks of sand brought up from the fissures, extending in various directions, dot the fields from side to side at intervals of 15 or 20 yards. It was immediately observed on reaching Summerville that the direction of destructive motion was vertical rather than horizontal; that the chimneys seldom appeared to have been thrown, but to have been simply crushed and then to have toppled over. Examples will be noted further on. The Episcopal church, in the southwestern part of the town, a wooden structure 30 by 50 feet, resting on thirty-six brick piers, each two and a half feet square and four feet high, fronting N. 70° E., has been displaced northward two and a half inches at the west end and one and three-quarters inches in the middle and one inch at the east end. This northward displacement of the church has not carried with it any of the nine pillars under the south wall, but one or two of the pillars under the north wall and several of those beneath the church have partaken of its movement. Several

of the pillars, however, exhibit crushing at their summits, and a few have oblique fissures through them, extending from the south obliquely downward to the north. The crushing is more pronounced in the pillars beneath the four corners, and is nil in many of them beneath the floor and under the front of the light wooden portico.

"The houses in Summerville are of wood, and supported on pillars either of wood or brick, five to seven feet in height; the chimneys being generally independently supported by arches or piers built up from the ground. The main building is commonly surrounded, partially or wholly, by a piazza supported on columns like those beneath the house, but usually more slender. This description applies to Colonel Gregg's house, the injuries to which will be fully described, as they may be regarded as representative of what happened to many others. The building has piazzas on the west, south and east, and a shed-roof or lean-to on the north. The pillars of the main building and piazza are of brick, but those under the lean-to are round logs 10 to 12 inches in diameter. Two large chimneys in the main building are independent. The whole building has been displaced one or two inches to the northward. The west end has moved on the piers, while the east end has carried the piers with it, and they are now inclined two inches from the vertical. All of the piers under the heavier portions of the house, and particularly the corner-posts, are crushed at their summits, driven perceptibly into the ground and fissured obliquely, and several of them have fallen. The piers beneath the piazza and some of those beneath the floor are but slightly injured, and at the time of examination supported the weight of the house. Portions of both chimneys which projected above the roof were thrown northward and both crashed through the roof of the shed and one of them through its floor, a section of the chimney four feet long standing upright but in reversed attitude on the ground beneath the house. The projecting part of the other chimney was completely shattered. The basal portion of one of the chimneys is crushed, intersected by oblique cracks, and is spread laterally five or six inches. The basal portion of the other is completely crushed, and the entire chimney from one foot above the ground to the level of the roof has collapsed into a conical heap of loose bricks about the base. Wooden pillars supporting the lean-to are of sound pine, and were set into the earth to a depth of two or three feet. The condition of the earth about the bottoms of these posts indicates that they have been swung in all directions, compressing the earth on all sides, and finally returning approximately to their original positions, leaving an annular space between the post and the compressed earth of perhaps an inch in width. Some of the smaller brick piers, which extend several inches below the ground, appear to have swung with the main building in like manner, forming open crevices between the brick and earth on all sides. Some of them appear to have been driven into the earth with such force as to produce a depression of the surface for six inches or a foot in all directions from them, with occasional curved concentric fissures.

The simile of concentric ripples on a pond may be applied again in describing the effects of the earthquake with increasing distance from the center of disturbance. Near Charleston the impulse was powerfully destructive; in neighboring states the shocks were strong but did no material damage; and in more distant parts of the country they were slight or imperceptible. However, the radius of the area within which most of the inhabitants were startled was surprisingly large, as indicated by the following press despatches and notes (Dutton, 1888, pp. 334, 335, 341-342, 346):

In western Massachusetts and in Connecticut all the larger cities and towns indicate that its effects were very perceptible, but usually in the upper stories of high buildings. The smaller towns, which seldom contain high buildings, generally give negative reports. In the valley of the Hudson and in northern New Jersey the shaking was much more noticeable and was far more generally observed. In New York City thousands of people were aware of it in spite of the incessant jar and rumble which characterize the metropolis. The account given by the *New York Herald* is worth preserving.

(New York Herald, September 1, 1886)

In the city department of the Herald building, on the third floor, the oscillations were felt with alarming distinctness. As nearly as can be judged it was five minutes to 10 o'clock. . . . The motion was so well defined that it was sufficient at each recurrence to press some of the writers who were at work against the tables. Electric wires suspended about the room swayed back and forth. A heavy electric lamp, covered with a screen and standing on a slender brass rod, swayed laterally to and fro with a sweep of three-quarters of an inch for more than fifty seconds. There were two series of vibrations, the first lasting about twenty seconds. Then there was an interval of four or five seconds, and again a series of stronger oscillations covering perhaps thirty-five or forty seconds. While the first series lasted only two or three of those who were present seemed to be aware of it. They began to ask each other, "What was that?" "Did you feel that tremor?" and similar questions, and then it ceased. But while they were still questioning each other and discussing the second series of earth waves set in, and then all who were present felt the motion and saw the swaying of objects in the room. The duration of this second series was such that persons could move about the room watching the manifestations of the earth's erratic action.

No State has given fuller or more satisfactory reports than Ohio. And there is hardly a town in it which did not feel the earthquake. As might be expected, it was more forcible in the southern parts than in the northern; but even in the northern parts it is rather a matter of surprise that they were so well marked. In Cleveland and in the surrounding towns and villages it appears to have displayed rather abnormal force.

(New York Times, September 1, 1886)

CLEVELAND, OHIO, August 31.

A very strong shock of earthquake was felt here at 9:30 o'clock to-night, lasting perhaps fifteen seconds. People rushed out of their houses into the streets precipitately, the theaters were emptied, meetings were suddenly broken up, and a feeling akin to panic was general throughout the city, though no damage is reported. Everybody felt the nausea and dizziness which commonly accompany such shocks. The undulations were about east and west, and not less than three, though little definite testimony on that point is ascertainable on account of the unexpectedness of the phenomenon and the attendant excitement. Telegrams show that probably the whole State was shaken up.

The entire population were simultaneously seized with a sensation of dizziness and weakness, which was attributed to a sudden attack of illness, and the rocking motion plainly felt was at first ascribed to a deranged physical system. Houses were moved and everything within them. In some instances walls cracked with a startling noise, while in a few cases small fissures opened. A considerable number of people who were standing fell down. Persons on the ground felt light-headed, but many did not notice the undulations, though nearly every one had stomach qualms. The higher one was from the ground the greater was the motion. Everything hanging swung with violence, and the gas went out in some places and clocks stopped. In the Academy of Music a serio-comic singer had just begun his song when the audience as one man arose and scrambled out of doors, greatly to the performer's chagrin. A lodge of colored Odd Fellows was in the midst of initiating a candidate. The ceremony abruptly ended, and the entire body rushed down-stairs in full regalia, leaving the candidate powerfully impressed. Billiard players were startled at observing the balls take most erratic courses. Not a few who had retired for the night were suddenly anxious for fresh air and terra firma. They neglected to arrange their toilets, and gave a ghostly appearance to their vicinity. The telephone exchanges were emptied of operators, and it was some minutes before subscribers could call one another. Then everybody wanted to call up somebody and inquire what the matter was. Many an amusing scene occurred in saloons, customers unceremoniously abandoning their waiting liquor and striding into the street. When all danger was past people compared notes and enjoyed the fun of the thing, but for a few moments the most intense and trying seriousness prevailed.

. . . It will be of interest here to note the intensity in the southeastern part of Missouri, in the vicinity of New Madrid, which was in the epicentral tract of the great earthquakes of 1811-'12. We shall thus be enabled to make some comparison between these two great earthquakes.

Let us first recall the effects of the New Madrid earthquake in Charleston. A careful comparison of the accounts preserved indicate that they were as violent at least as that of the Charleston earthquake in Atlanta, Asheville, Raleigh, and Wilmington. The accounts given by localities situated about two hundred miles from Charleston approximate very closely the indicated intensity of the New Madrid earthquake in Charleston. The distance between the epicentra of the two earthquakes is about six hundred miles. At New Madrid the Charleston earthquake was felt only as a very feeble tremor, noticed indeed by a number of persons, but exciting no comments at the time, because such tremors are felt there rather frequently. It will thus be seen that the New Madrid earthquake was a convulsion vastly exceeding that of Charleston.

If New York City should be visited by an earthquake of the first magnitude, the awfulness of the catastrophe can hardly be imagined. Several writers, some of them earthquake specialists, have entertained with some seriousness this unattractive possibility, and have attempted to sound a warning against the building of high structures without strength to resist the peculiar strains set up by earthquakes. Their apprehension for New York is based chiefly on the occurrence of destructive shocks in unexpected places, such as Charleston. Nothing in the recorded history of New York would justify expectation of any such catastrophe to the metropolis. No earthquake of alarming intensity has been experienced by Manhattan Island since the first settlements were established. However, it is not impossible that its seeming stability is deceptive.

It is fortunate, from a human viewpoint, that many of the severest shocks occur in sparsely settled regions. If the New Madrid earthquake of 1811 had centered in New England or in the vicinity of London, and not in the Mississippi flood plain, it would now be rated as one of the major disasters in all history. This was a shock of terrible intensity, as indicated by the following summary account (Fuller, 1912, pp. 10-11):

> The evening of December 15, 1811, in the New Madrid area [southern Missouri] was clear and quiet, with no unusual conditions which could be regarded as portending the catastrophe soon to take place. A little after 2 o'clock on the morning of December 16, the inhabitants of the region were suddenly awakened by the groaning, creaking, and cracking of the timbers of the houses or cabins in which they were sleeping, by the rattle of furniture thrown down, and by the crash of falling chimneys. In fear and trembling they hurriedly groped their way from their houses to escape the falling debris, and remained shivering in the winter air until morning, the repeated shocks at intervals during the night keeping them from returning to their weakened or tottering dwellings. Daylight brought little improvement to their situation, for early in the morning another shock, preceded by a low rumbling and fully as severe as the first, was experienced. The ground rose and fell as earth waves, like the long, low swell of the sea, passed across its surface, tilting the trees until their branches interlocked and opening the soil in deep cracks as the surface was bent. Landslides swept down the steeper bluffs and hillsides;

considerable areas were uplifted, and still larger areas sank and became covered with water emerging from below through fissures or little "craterlets" or accumulating from the obstruction of the surface drainage. On the Mississippi great waves were created, which overwhelmed many boats and washed others high upon the shore, the return current breaking off thousands of trees and carrying them out into the river. High banks caved and were precipitated into the river, sand bars and points of islands gave way, and whole islands disappeared.

During December 16 and 17 shocks continued at short intervals but gradually diminished in intensity. They occurred at longer intervals until January 23 when there was another shock, similar in intensity and destructiveness to the first. This shock was followed by about two weeks of quiescence, but on February 7 there were several alarming and destructive shocks, the last equaling or surpassing any previous disturbance, and for several days the earth was in a nearly constant tremor.

For fully a year from this date small shocks occurred at intervals of a few days, but as there were no other destructive shocks the people gradually became accustomed to the vibrations and gave little or no further attention to them.

The nature of the New Madrid shocks is further illuminated by the following paragraphs (Heck, 1928, pp. 38, 39, 40, 41):

The record goes back only to 1776 when a shock of moderate intensity occurred. There were similar ones in the nineties and in the first decade of the following century. These caused the Indians to predict a great earthquake, the prediction being based on the Indian tradition of a great earthquake at an earlier date. The geological evidence confirms this, though the date can not be fixed. This illustrates a weakness in our earthquake history as compared with Europe and parts of Asia where the records are fairly good for 2,000 years.

The most seriously affected area was characterized by raised and sunk lands, fissures, sinks, sand blows, and large landslides. This area was 30,000 to 50,000 square miles in extent, extending from a point west of Cairo to the latitude of Memphis and from Crowleys Ridge to Chickasaw Bluffs, a distance of 50 miles.

Caving of river banks occurred as far away as Vicksburg. The shock was felt from Canada to New Orleans and from the headwaters of the Missouri to the Atlantic, including Boston, 1,100 miles away. About 1,000,000 square miles, or half the area, was so shaken that vibrations were distinctly felt. This far exceeds in area any other known earthquake of this continent.

Naturally the record is very incomplete, but there is little doubt that at New Madrid and Caruthersville the soil was so broken that cultivation was impossible and the inhabitants feared to rebuild their houses during the period of the severe shocks. There is a definite record that the shocks lasted through at least two years as a very good record was kept at Louisville, the effect on a number of pendulums having been noted by Jared Brooks and a record of the weather conditions also kept. There is evidence that the Mississippi Valley was severely and even dangerously shaken in places outside of the area of maximum effect.

The shock of December 16 was distinctly felt in Washington, D. C., and people were badly frightened. It is of special interest that Charleston was quite severely shaken, in view of the earthquake here of 75 years later. As might be expected, the western parts of the southern Atlantic States were more severely shaken than the eastern. The shocks were moderate in the northern Atlantic States, though felt at Baltimore and Boston. This apparently is connected with the relation of the Appalachian system to the epicenter of the earthquake. This effect has been noticed in less degree in the Charleston earthquake of 1886 and the St. Lawrence Valley shock of 1925.

In spite of the great intensity of the earthquake, the loss of life was insignificant. In an earthquake at Caracas during the same period 10,000 lives were lost. At New Madrid only

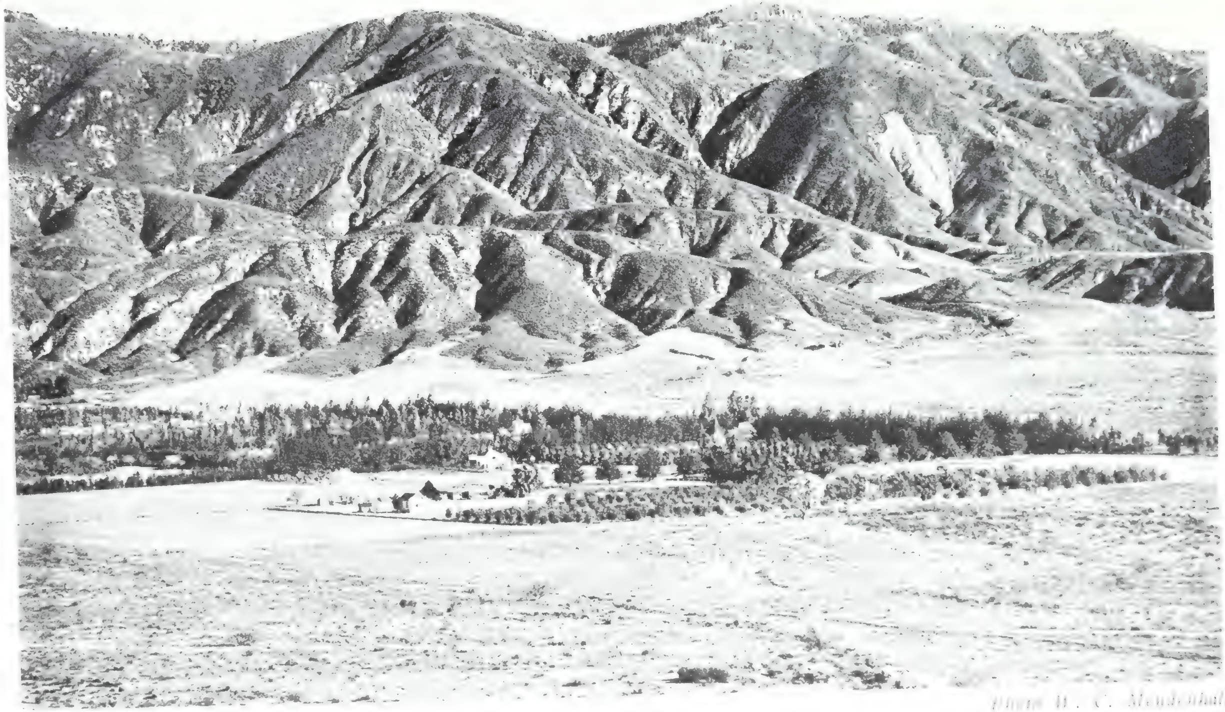


Photo W. C. Mendenhall

ERODED FAULT SCARP

The San Bernardino Mountains, California. Since the last movement on the fault, erosion has modified the scarp. The "Arrowhead" was made by a landslide which removed the vegetation over a large arrow-shaped area.

PLATE XXXV

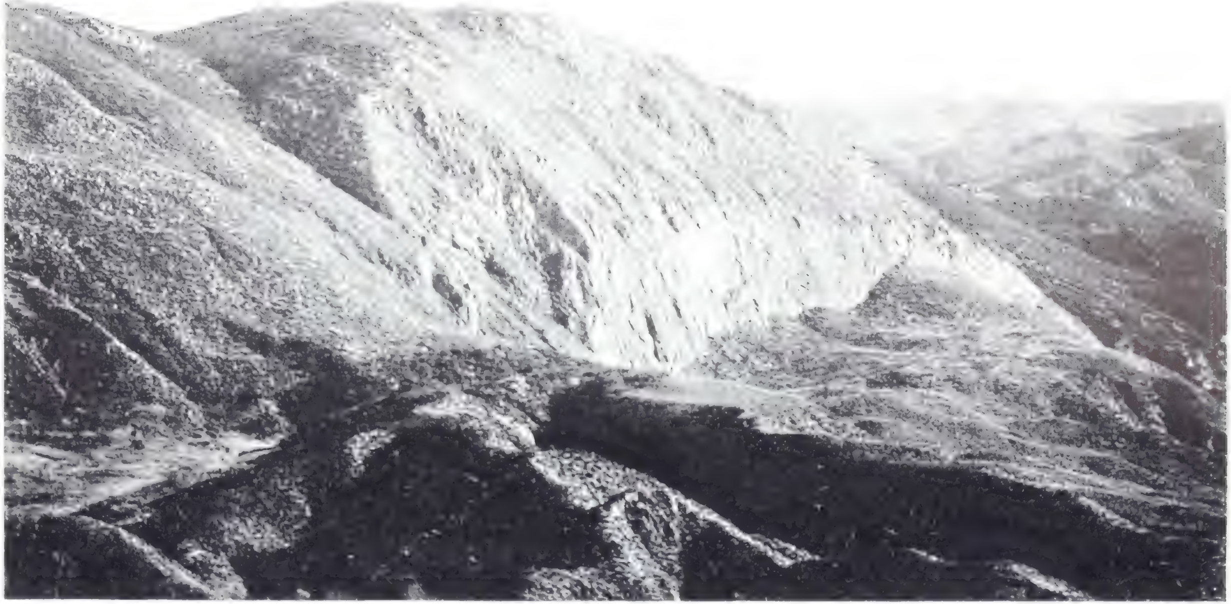


Photo W. C. Mendenhall

A NEW FAULT SCARP

Made by recent local displacement in the San Bernardino Mountains, California.

1 life was lost through falling buildings. Of course, the log cabin, the more common type of building at this time, was peculiarly suited to withstand earthquake damage. Several persons were thrown into the river by caving banks and drowned and a number of boatmen were lost when their boats sank. A number of canoes were seen drifting, their occupants having probably drowned.

There seems to have been periods of darkness, but these were probably due to rising clouds of dust. There is little doubt that sulphur gas due to buried vegetation escaped from many of the crevices. Flashes of light were reported at various places, but the evidence indicates that this was lightning, as there were no such reports from places having clear weather.

According to contemporary accounts, waves with visible depressions between the swells rolled across the earth which finally broke open leaving parallel fissures. Another type of smaller size resulted from the settling and caving of river banks. The former type were reported to be from 600 to 700 feet long with one having a length of 5 miles. In some cases persons were rescued with difficulty. There was also another type of fissure consisting of a long narrow block dropping and leaving a trench with vertical sides. All types have been found filled with sand, and so we are not dependent on contemporary accounts.

Water waves of considerable size were caused on the Mississippi. Starting from different points they met and caused a sharp wall-like chop. Fissures opened and closed below the surface, sending out waves. Waves moving upstream and local uplifts caused an appearance of the river flowing upstream. Even ponds showed a troubled surface during the shock.

Caving of banks, disappearance of islands, lifting of snags long buried, and floating trees brought into the river by landslides made navigation precarious until conditions settled down and the pilots learned the changes.

> Many trees were overthrown by slides and many were split. In some cases, trees were thrown over to a sharp angle by slides, then when the slide came to rest they started to grow in the new position, the lower parts of the trunks being inclined and the upper parts vertical. In some places the vibration alone threw the trees down. Over the sunken country trees were killed by overflowing of lower parts of trunks. Forests were probably destroyed over an area of 150,000 acres.
>
> A distant rumbling is described. The emission of water was accompanied by a hissing and whistling, and noises like the discharge of a cannon, the rumbling of distant thunder, and like the sound of a carriage passing through the street were heard.

Every great earthquake excites in the minds of laymen various speculations as to the immediate cause. Many extravagant hypotheses are advanced, most of them untenable to scientific students of the subject. Within the last few years newspapers and newsreels have given wide publicity to unscientific guesses of this kind. In 1923, for example, a reel showing effects of the great Tokyo earthquake was prefaced by the following dogmatic statement of the cause: A great fissure opened suddenly in the ocean floor east of Japan; ocean water rushed into this opening, and, penetrating to red-hot rocks miles below, exploded! Obviously any weakening of such a dramatic explanation by discreet reservations would spoil it for purposes of sensational news.

Popular and professional views as to the origin of the New Madrid shocks are discussed by Fuller (1912, pp. 102-105):

> Of the various explanations offered by those who speculated on the causes of the shock the volcanic theory was, as usual, by far the most popular. The general nature of volcanic manifestations was more or less understood by everybody, while relatively few had heard of the slower processes of warping and folding and the occurrence of faulting and even those who had seldom appreciated their importance. It is but natural,

therefore, that they should turn for an explanation to the known cause which seemed to explain the phenomena best. It is probably to this general belief in the volcanic origin of the shock that the stories of the emission of sparks and similar phenomena are to be attributed.

One of the best evidences of the origin of the New Madrid earthquake is the nature of the vibrations. If they had resulted from a disturbance within the alluvial deposits themselves, it could have been only from such causes as the expulsion of water and gases, the caving of banks, the slipping of landslides, etc. In regard to the first, it need only be repeated that there is no evidence of any extrusions of water or gas, except those arising in consequence of disruptions brought about by (not causing) the shocks. Of the caving of banks it may be said that had the shores of the Mississippi caved from source to mouth the vibrations would have been felt only a few hundred feet. Similarly in regard to the landslides. Although the faces of the Chickasaw Bluffs were affected for miles, it was by slipping and not by direct fall, and the jar, if any was produced at all, could have been felt only a short distance. The vertical vibrations accompanying several of the shocks were of a nature differing from any which we can conceive as developing in the unconsolidated deposits themselves.

The best evidence of origin is that afforded by the distance to which the vibrations were felt. It does not seem possible to conceive of a shock originating in soft embayment deposits being transmitted to the hard rocks and thence across the Appalachians to the Atlantic coast on the east and across the central coal basin to Chicago, Detroit, and Canada. The fact that the shocks were strongly felt at these localities seems to point conclusively to a deep-seated origin in rigid rocks. A faulting in the hard Paleozoic rocks seems, therefore, to be the only probable explanation.

> . . . The New Madrid earthquake was but one of a series that is still unfinished, indicating that in all probability it resulted from causes that are still active. Inasmuch as the center of activity of the primary shocks is within the embayment area and well removed from the surrounding areas of consolidated rocks, it seems clear that the ultimate cause lies in forces operating beneath the embayment deposits. The action may be associated either with the processes of folding or warping or incident to a depression and deepening of the basin.

Major earthquakes near Atlantic coasts and in the interior of North America are exceptional; in and around the Pacific Ocean basin they are commonplace. Chile, Central America, California, Japan, the East Indies—these are only a few of the areas visited by disastrous shocks in modern times. Alaska and the Aleutian Islands share the unstable reputation of the Pacific borders in general.

One of the Alaskan shocks ranks with the greatest in history, although the name Yakutat is less familiar than Messina and Tokyo in connection with earthquakes. Few people experienced the great Alaskan cataclysm in the zone of high intensity, and it passed with little notice except on the part of technical students. The paragraphs that follow are taken from the detailed account prepared by two geologists (Tarr and Martin, 1912, pp. 11, 31, 79):

> During the month of September, 1899, the region near Yakutat Bay, Alaska, was shaken by a series of severe earthquakes—so severe, indeed, that it seems probable that in the minds of geologists the name Yakutat will always be associated with these earthquakes rather than with the grand glaciers, fiords, mountain scenery, or any other features of the bay. The cause of these shocks was undoubtedly the renewal of growth in the St. Elias Range, one of the youngest and loftiest of mountain ranges.
>
> Fortunately there was no great city near by, and in the small village nearest at hand there was no loss of life. Nor was there any injury to the few men who happened to be near

the center of disturbance during several of the most severe shocks.

These earthquakes were attended by two notable results—great changes in the level of the land, incidental to faulting, and remarkable accompanying and subsequent changes in the adjacent glaciers. . . .

The changes of level are the greatest recorded in historical times,[1] the maximum uplift amounting to over 47 feet. The changes in the glaciers include a rapid retreat of Muir Glacier, 150 miles to the southeast, and a general advance of several glaciers near Yakutat Bay. Muir Glacier, which hundreds of travelers had visited annually up to 1899, became inaccessible to tourist vessels in that year and remained so till 1907. By 1903 it had retreated from 2½ to 3 miles, and by 1907 from 7½ to 8 miles, perhaps in part as an indirect result of this earthquake, and had lost much of its scenic interest. The advance of the glaciers near Yakutat Bay included the eastern or Marvine lobe of the great Malaspina Glacier and rendered that highway of glacier travel inaccessible through intricate crevassing.

On the west shore of Disenchantment Bay the first rock cliff south of Turner Glacier, less than half a mile from the ice front, shows an uplift of 33 feet 11 inches; and within 1½ miles from that point this remarkable uplifted shore line, the most perfect as well as the highest in the region, attains an elevation of 47 feet 4 inches. Just below Bancas Point the elevation is 42 feet; south of that, on the alluvial fan of the Black Glacier stream, it rapidly descends.

The heaviest shock as felt at the village of Yakutat, 30 miles from Disenchantment Bay, is described by C. E. Hill as follows:

---

[1] This statement is no longer true. Displacements associated with the Tokyo earthquake, 1923, were many times greater. So far as known, however, the Yakutat displacement is the greatest that is known to have affected solid rock.—Ed. Note.

"This was the shake that did all the damage. We were in our tent, and to give you some idea of the violence of the quake, we could not get up and stand on our feet at first. The mission rocked until the church bell rang, and if anything was needed to complete the terror of the natives it was the ringing of the bell. Just as the earthquake ceased we saw a wonderful thing happen on the bay. From the ocean began rolling in great tidal waves. There were three of them following each other at intervals of about five minutes, and we stood and watched the bay rise 15 feet, from low tide to a foot above the highest tide point. The bay itself was full of whirlpools that were whirling trees, lumber, and driftwood around and around so fast that the eye could hardly follow them. They circled around like a flash while the water was churned into a mass of seething foam. The whirlpool caught the chute of a sawmill a short way below us and ripped it away in a twinkling.

"Just across from Yakutat in the bay is the island of Kanak (Khantaak). On the shore of this island was situated an old Indian graveyard, up about 6 feet above the highest tide mark. It was out on a point and we suddenly noticed that the point, graveyard, and all had disappeared, sunk out of sight. There was in the graveyard a very high pole with a cross on the top, and we soon discovered this way out in the water, some 4 or 5 feet of it sticking out of the water and still upright. (I would guess that 25 acres or more of the built-up sand on the inside of the point sunk to a depth of 20 feet or less.) The next day we took a boat and rowed over to the island. Our boat was rowed right over the place where the graveyard had formerly been, and looking down into the water we could see the tops of (brush spruce) trees. In several places we made soundings and were unable to get bottom at all (with an oar).

"We then rowed down to the mouth of the harbor to a place called Ocean Cape. Here we found the shore plowed with great furrows about 4 feet apart. Originally they must have been 20 feet in depth, but the sandbanks had caved in on them and filled them up until they were only 4 or 5 feet deep when we saw them. A little farther along the shore we found the marks of a number of gigantic waterspouts (which left holes 4 or 5 feet deep). They had bored great holes into the sand and had carried the sand and earth inland and scattered it 6 inches deep over acres of ground. From every indication the force of the waterspouts and waves must have been irresistible, and Yakutat must surely have been washed away had the tidal waves swept the bay at high instead of low tide.

"The earthquake was undoubtedly a magnificent sight, but hardly one a fellow would hunt up for the sake of looking at it. The Indians are frightened out of their wits and many of them have already left the place."

At the time of the Yakutat earthquake fault scarps were formed across stream beds, making waterfalls of considerable height. Such features at a distance from the sea coast record merely relative movement; ordinarily it is not possible to say whether one side of the fault moved up or the other down. Along the shore, however, both the direction and the amount of displacement were clearly indicated. Some of the evidence is explained by Tarr and Martin (1912, p. 22):

> It seems doubtful whether barnacles have ever before served as an evidence of faulting, as they have done along the shores of Yakutat Bay. Here dead forms of two species still cling to the rocks of the elevated shore lines, in many places in far greater abundance than the living forms at present sea level. Few of the living barnacles have attained a diameter of over three-eighths of an inch, and they contrast strongly with the giant dead barnacles, many of which are 1½ inches in diameter. The forms were well preserved in 1905, six years after they were killed by being hoisted out of the reach of salt water; in many of them the valves were still held together by the organic tissue, though most retained only the outer shell.
>
> These white shells, firmly attached to the rocks upon which they grew till 1899 are a striking feature along the shores of

the fiord, especially upon precipitous and overhanging cliffs. They are rarely absent where other evidence suggests that the shore lines have been uplifted, except where the ledges are weathering too rapidly to retain them, and they are usually the first evidence of uplift seen from a boat, though in some places they were hidden in 1905 by annual plants and by 4 or 5 year willow and alder shrubs.

Dead barnacles no longer attached to the rocks are not convincing evidence of uplift, nor are the dead barnacles adhering to beach bowlders, because such objects might be thrown up during an earthquake wave to a point higher than the sea level where the barnacles lived. The barnacles on bowlders were never accepted as evidence of uplift during our study, unless others were found adhering to the adjacent ledges at points equally high.

It was the dead barnacles fastened to the ledges among grasses and alder shrubs that first called our attention to the change of level, for we noted these even before we had observed any of the uplifted physiographic forms or had recognized other biologic evidence or had gathered evidence from men. The barnacles were even more important as the chief source of specific information with regard to the amount of uplift at various points and in this way were markers for the faulting.

The west coast of South America marks a zone of large and repeated movement. Exceptionally deep water near the shore indicates profound subsidence, and old strand lines high above sea level record uplift on the landward side. Frequent severe earthquakes show that the movement is still in progress, and that it is not steady but pulsatory or jerky in character.

A powerful shock which occurred more than a century ago is described by Lyell (1860, pp. 457-458):

Chili, 1822.—On the 19th of November, 1822, the coast of Chili was visited by a most destructive earthquake. The shock was felt simultaneously throughout a space of 1,200 miles from north to south. St. Jago, Valparaiso, and some other places, were greatly injured. When the district round Valparaiso was examined on the morning after the shock, it was found that the coast for a considerable distance was raised above its former level. At Valparaiso the elevation was three feet, and at Quintero about four feet. Part of the bed of the sea, says Mrs. Graham, remained bare and dry at high water, "with beds of oysters, mussels, and other shells adhering to the rocks on which they grew, the fish being all dead, and exhaling most offensive effluvia."

An old wreck of a ship, which before could not be approached, became accessible from the land, although its distance from the original sea-shore had not altered. It was observed that the water-course of a mill, at the distance of about a mile from the sea, gained a fall of fourteen inches, in little more than one hundred yards; and from this fact it is inferred that the rise in some parts of the inland country was far more considerable than on the borders of the ocean. Part of the coast thus elevated consisted of granite, in which parallel fissures were caused, some of which were traced for a mile and a half inland. Cones of earth about four feet high were thrown up in several districts, by the forcing up of water mixed with sand through funnel-shaped hollows,—a phenomenon very common in Calabria, and the explanation of which will hereafter be considered. Those houses in Chili of which the foundations were on rock were less damaged than such as were built on alluvial soil.

Mr. Cruickshanks, an English botanist, who resided in the country during the earthquake, has informed me that some rocks of greenstone at Quintero, a few hundred yards from the beach, which had always been under water till the shock of 1822, have since been uncovered when the tide is at half-ebb: and he states that, after the earthquake, it was the general belief of the fisherman and inhabitants of the Chilian coast, *not* that the land had risen, but that the ocean had permanently retreated.

Dr. Meyen, a Prussian traveller, who visited Valparaiso in 1831, says that on examining the rocks both north and south of the town, nine years after the event, he found, in corroboration of Mrs. Graham's account, that remains of animals and sea-weed, the *Lessonia* of Bory de St. Vincent, which has a firm ligneous stem, still adhered to those rocks which in 1822 had been elevated above high-water mark. According to the same author, the whole coast of Central Chili was raised about four feet, and banks of marine shells were laid dry on many parts of the coast. He observed similar banks, elevated at unknown periods, in several places, especially at Copiapo, where the species all agree with those now living in the ocean. Mr. Freyer also, who resided some years in South America, has confirmed these statements; and Mr. Darwin obtained evidence that the remains of an ancient wall, formerly washed by the sea, and now 11½ feet above high-water mark, acquired several feet of this additional elevation during the earthquake of 1822.

The shocks continued up to the end of September, 1823; even then, forty-eight hours seldom passed without one, and sometimes two or three were felt during twenty-four hours. Mrs. Graham observed, after the earthquake of 1822, that besides a beach newly raised above high-water mark, there were several older elevated lines of beach, one above the other, consisting of shingle mixed with shells extending in a parallel direction to the shore, to the height of fifty feet above the sea.

India and China, both densely populated for many centuries, have felt the scourge of earthquakes. The great Indo-Gangetic flood plain, stretched in front of the highest mountains of the Earth, supports the large majority of India's millions; and in this level alluvial country some important earthquakes have wrought havoc with man and his works. Lyell (1860, pp. 459-460) describes some unusual changes in the landscape during one of these events:

Cutch, 1819.—A violent earthquake occurred at Cutch, in the delta of the Indus, on the 16th of June, 1819. The principal town, Bhooj, was converted into a heap of ruins, and its stone buildings were thrown down. The movement was felt over an area having a radius of 1,000 miles from Bhooj, and extending to Khatmandoo, Calcutta, and Pondicherry. The vibrations were felt in Northwest India, at a distance of 800 miles, after an interval of about fifteen minutes after the earthquake at Bhooj. At Ahmedabad the great mosque, erected by Sultan Ahmed nearly 450 years before, fell to the ground, attesting how long a period had elapsed since a shock of similar violence had visited that point. At Anjar, the fort, with its tower and guns, was hurled to the ground in one common mass of ruin. The shocks continued until the 20th; when, thirty miles northwest from Bhooj, the volcano called Denodur is said by some to have sent forth flames, but Captain Grant was unable to authenticate this statement.

Subsidence in the Delta of the Indus.—Although the ruin of towns was great, the face of nature in the inland country, says Captain Macmurdo, was not visibly altered. In the hills some large masses only of rock and soil were detached from the precipices; but the eastern and almost deserted channel of the Indus, which bounds the province of Cutch, was greatly changed. This estuary, or inlet of the sea, was, before the earthquake, fordable at Luckput, being only about a foot deep when the tide was at ebb, and at flood-tide never more than six feet; but it was deepened at the fort of Luckput, after the shock, to more than *eighteen feet at low water.* On sounding other parts of the channel, it was found, that where previously the depth of the water at flood never exceeded one or two feet, it had become from four to ten feet deep. By these and other remarkable changes of level, a part of the inland navigation of that country, which had been closed for centuries, became again practicable.

Ancient Views of Earthquakes

The ancients tried to explain what they saw and experienced, and the dwellers in lands subject to earthquakes naturally sought an explanation of these terrifying phenomena. It is not surprising that their uneducated minds ordinarily attributed earthquakes to some mysterious supernatural force. Philosophers like Aristotle were convinced that natural forces are responsible; but their gropings for the truth did not lead them far on the right road. They were handicapped by a general ignorance of scientific principles as well as of facts. In their philosophy all natural phenomena must be explained in terms of the four "elements" —earth, air, fire, and water. The following quotation from Aristotle's *Meteorologica* (Webster, 1923, pp. 7, 365 a) illustrates his courage but also his sad limitations:

> We must go on to discuss earthquakes next, for their cause is akin to our last subject [winds].
>
> The theories that have been put forward up to the present date are three, and their authors three men, Anaxagoras of Clazomenæ, and before him Anaximenes of Miletus, and later Democritus of Abdera.
>
> Anaxagoras says that the ether, which naturally moves upwards, is caught in hollows below the earth and so shakes it, for though the earth is really all of it equally porous, its surface is clogged up by rain. This implies that part of the whole sphere is "above" and part "below": "above" being the part on which we live, "below" the other.
>
> This theory is perhaps too primitive to require refutation. It is absurd to think of up and down otherwise than as meaning that heavy bodies move to the earth from every quarter, and light ones, such as fire, away from it; especially as we see that, as far as our knowledge of the earth goes, the horizon always changes with a change in our position, which proves that the earth is convex and spherical. It is absurd, too, to maintain that the earth rests on the air because of its size, and then to say that impact upwards from below shakes it right through. Besides he gives no account of circumstances attendant on

earthquakes: for not every country or every season is subject to them.

Democritus says that the earth is full of water and that when a quantity of rain-water is added to this an earthquake is the result. The hollows in the earth being unable to admit the excess of water it forces its way in and so causes an earthquake. Or again, the earth as it dries draws the water from the fuller to the emptier parts, and the inrush of the water as it changes its place causes the earthquake.

Anaximenes says that the earth breaks up when it grows wet or dry, and earthquakes are due to the fall of these masses as they break away. Hence earthquakes take place in time of drought and again of heavy rain, since, as we have explained, the earth grows dry in time of drought and breaks up, whereas the rain makes it sodden and destroys its cohesion.

But if this were the case the earth ought to be found to be sinking in many places. Again, why do earthquakes frequently occur in places which are not excessively subject to drought or rain, as they ought to be on the theory? Besides, on this view, earthquakes ought always to be getting fewer, and should come to an end entirely some day: the notion of contraction by packing together implies this. So if this is impossible the theory must be impossible too.

We have already shown that wet and dry must both give rise to an evaporation: earthquakes are a necessary consequence of this fact. The earth is essentially dry, but rain fills it with moisture. Then the sun and its own fire warm it and give rise to a quantity of wind both outside and inside it. This wind sometimes flows outwards in a single body, sometimes inwards, and sometimes it is divided. All these are necessary laws. Next we must find out what body has the greatest motive force. This will certainly be the body that naturally moves farthest and is most violent. Now that which has the most rapid motion is necessarily the most violent; for its swiftness gives its impact the greatest force. Again, the rarest body, that which can most readily pass through every other body, is that which naturally moves farthest. Wind satisfies these conditions in the highest degree (fire only becomes flame and moves rapidly when wind accompanies it): so that not water nor earth is the cause of earthquakes but wind—that is, the inrush of the external evaporation into the earth.

Hence, since the evaporation generally follows in a continuous body in the direction in which it first started, and either all of it flows inwards or all outwards, most earthquakes and the greatest are accompanied by calm. It is true that some take place when a wind is blowing, but this presents no difficulty. We sometimes find several winds blowing simultaneously. If one of these enters the earth we get an earthquake attended by wind. Only these earthquakes are less severe because their source and cause is divided.

Again, most earthquakes and the severest occur at night, or if by day, about noon, that being generally the calmest part of the day. For when the sun exerts its full power (as it does about noon) it shuts the evaporation into the earth. Night, too, is calmer than day. The absence of the sun makes the evaporation return into the earth like a sort of ebb tide, corresponding to the outward flow; especially towards dawn, for the winds, as a rule, begin to blow then, and if their source changes about like the Euripus and flows inwards the quantity of wind in the earth is greater and a more violent earthquake results.

The severest earthquakes take place where the sea is full of currents or the earth spongy and cavernous: so they occur near the Hellespont and in Achæa and Sicily, and those parts of Eubœa which correspond to our description—where the sea is supposed to flow in channels below the earth. The hot springs, too, near Ædepsus are due to a cause of this kind. It is the confined character of these places that makes them so liable to earthquakes. A great and therefore violent wind is developed, which would naturally blow away from the earth; but the onrush of the sea in a great mass thrusts it back into the earth. The countries that are spongy below the surface are exposed to earthquakes because they have room for so much wind.

For the same reason earthquakes usually take place in spring and autumn and in times of wet and of drought—because these are the windiest seasons. Summer with its heat and winter with its frost cause calm: winter is too cold, summer too dry for winds to form. In time of drought the air is full of wind; drought is just the predominance of the dry over the moist evaporation. Again, excessive rain causes more of the evaporation to form in the earth. Then this secretion is shut up in a narrow compass and forced into a smaller space by the water that fills the cavities. Thus a great wind is compressed into a smaller space and so gets the upper hand, and then breaks out and beats against the earth and shakes it violently.

The force wind can have may be gathered not only from what happens in the air (where one might suppose that it owed its power to produce such effects to its volume), but also from what is observed in animal bodies. Tetanus and spasms are motions of wind, and their force is such that the united efforts of many men do not succeed in overcoming the movements of the patients. We must suppose, then (to compare great things with small), that what happens in the earth is just like that.

Our theory has been verified by actual observation in many places. It has been known to happen that an earthquake has continued until the wind that caused it burst through the earth into the air and appeared visibly like a hurricane. This happened lately near Heracleia in Pontus and some time past at the island Hiera, one of the group called the Æolian islands. Here a portion of the earth swelled up and a lump like a mound rose with a noise: finally it burst, and a great wind came out of it and threw up live cinders and ashes which buried the neighbouring town of Lipara and reached some of the towns in Italy. The spot where this eruption occurred is still to be seen.

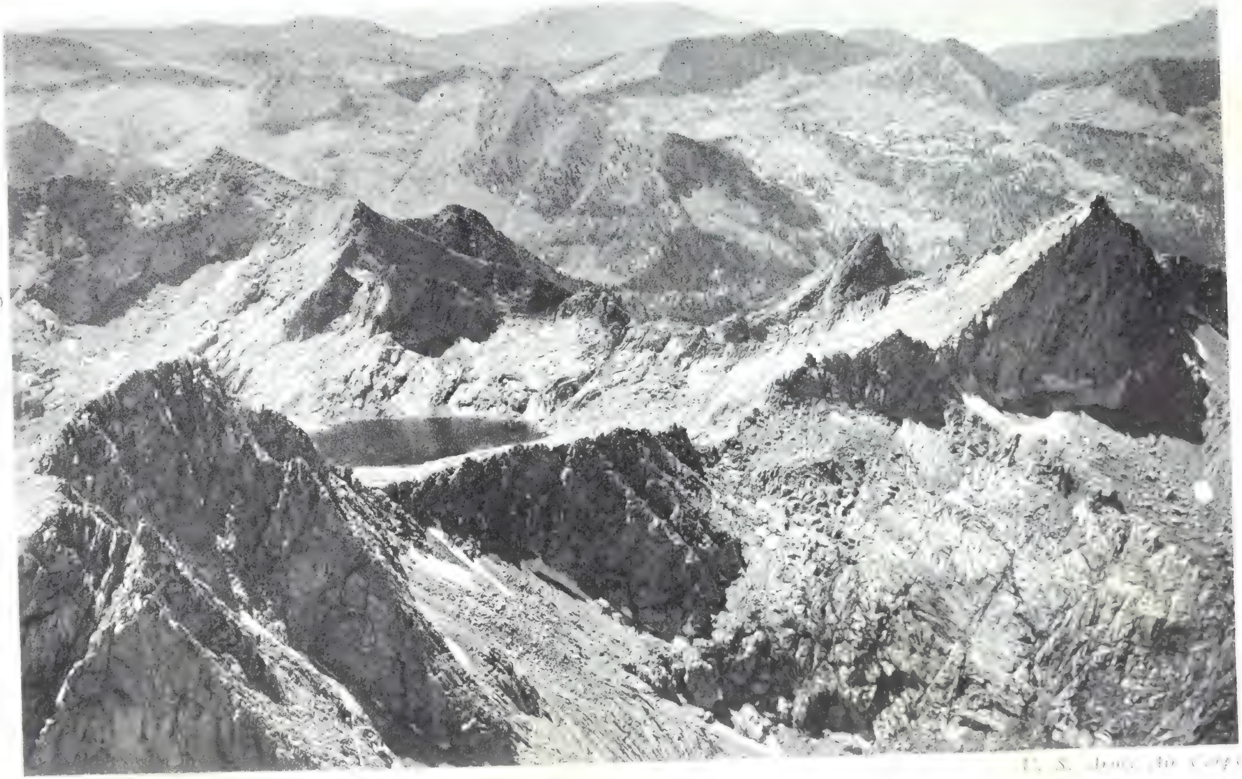
Slow Rising and Sinking of Land Areas

At the time of an earthquake a land surface may jump abruptly to a higher level or drop appreciably lower; and repetitions of movement in the same direction at any locality indicate a play of forces that will eventually cause radical changes in the landscape. Some of the lands bordering the Mediterranean Sea show evidences of notable change in altitude, and occurrences within historic time suggest continued uplift of wide areas, subsidence of others.

The old temple of Jupiter Serapis, at Pozzuoli, southern Italy, has long been famous for the clear evidence it furnishes of oscillations in the level of the land. Lyell visited the ruins of this temple and at the same time observed many other indications of crustal movement in that part of the Mediterranean coast. One of the clearest proofs consists of marine sediments which were laid down on parts of the old temple and on other works of man in the vicinity. Since these deposits are now well above the high-water level, they prove subsidence of the land and a later uplift. By studying historical records, Lyell was able to date some of the movements rather closely. Part of his detailed discussion on this subject (1860, pp. 511-516) is quoted here:

> Thus we arrive, without the aid of the celebrated temple, at the conclusion, that the recent marine deposit at Puzzuoli was upraised in modern times above the level of the sea, and that not only this change of position, but the accumulation of the modern strata, was posterior to the destruction of many edifices, of which they contain the imbedded remains. If we next examine the evidence afforded by the temple itself, it appears, from the most authentic accounts, that the three pillars now standing erect continued, down to the middle of the last century, almost buried in the new marine strata. The upper part of each protruding several feet above the surface was concealed by bushes, and had not attracted, until the year 1749, the notice of antiquaries; but, when the soil was removed in

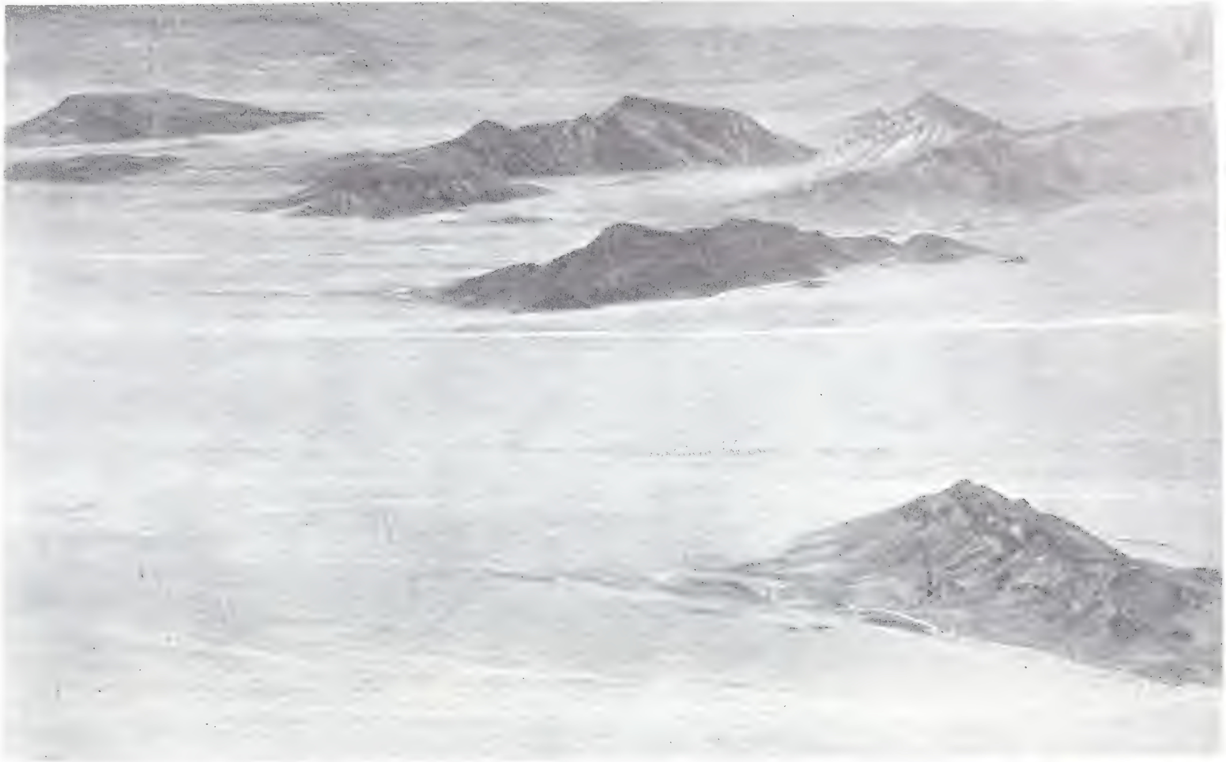
PLATE XXXVI



U. S. Army Air Corps

TOP OF THE SIERRA NEVADA

The rocks are granite, exposed by deep erosion after uplift. View west of Mount Whitney, California



U. S. Army Air Corps

BASIN RANGES

Mountains made by faulting and erosion, nearly buried in their own débris. Southern Nevada.

1750, they were seen to form part of the remains of a splendid edifice, the pavement of which was still preserved and upon it lay a number of columns of African breccia and of granite. The original plan of the building could be traced distinctly: it was of a quadrangular form, seventy feet in diameter, and the roof had been supported by forty-six noble columns, twenty-four of granite and the rest of marble. The large court was surrounded by apartments, supposed to have been used as bathing-rooms; for a thermal spring, still used for medicinal purposes, issues just behind the building, and the water of this spring appears to have been originally conveyed by a marble duct, still extant, into the chambers, and then across the pavement by a groove an inch or two deep, to a conduit made of Roman brickwork, by which it gained the sea.

. . . I shall . . . proceed to consider the memorials of physical changes inscribed on the three standing columns in most legible characters by the hand of Nature. These pillars, which have been carved each out of a single block of marble, are forty feet three inches and a half in height. A horizontal fissure nearly intersects one of the columns; the other two are entire. They are all slightly out of the perpendicular, inclining somewhat to the southwest, that is, towards the sea.[1] Their surface is smooth and uninjured to the height of about twelve feet above their pedestals. Above this is a zone, about nine feet in height, where the marble has been pierced by a species of marine perforating bivalve—*Lithodomus*. The holes of these animals are pear-shaped, the external opening being minute, and gradually increasing downwards. At the bottom of the cavities, many shells are still found, notwithstanding the great numbers that have been taken out by visitors; in many the valves of a species of arca, an animal which conceals itself in small hollows, occur. The perforations are so considerable in depth and size, that they manifest a long-continued abode of the lithodomi in the columns, for, as the inhabitant grows older and increases in size, it bores a larger cavity, to correspond with the increased magnitude of its shell. We must, consequently, infer a long-continued immersion of the pillars in sea-water, at a time when the lower part was covered up and protected by marine, fresh-water, and volcanic strata, afterwards to be described, and by the rubbish of buildings; the highest part, at the same time projecting above the waters, and being consequently weathered, but not materially injured.

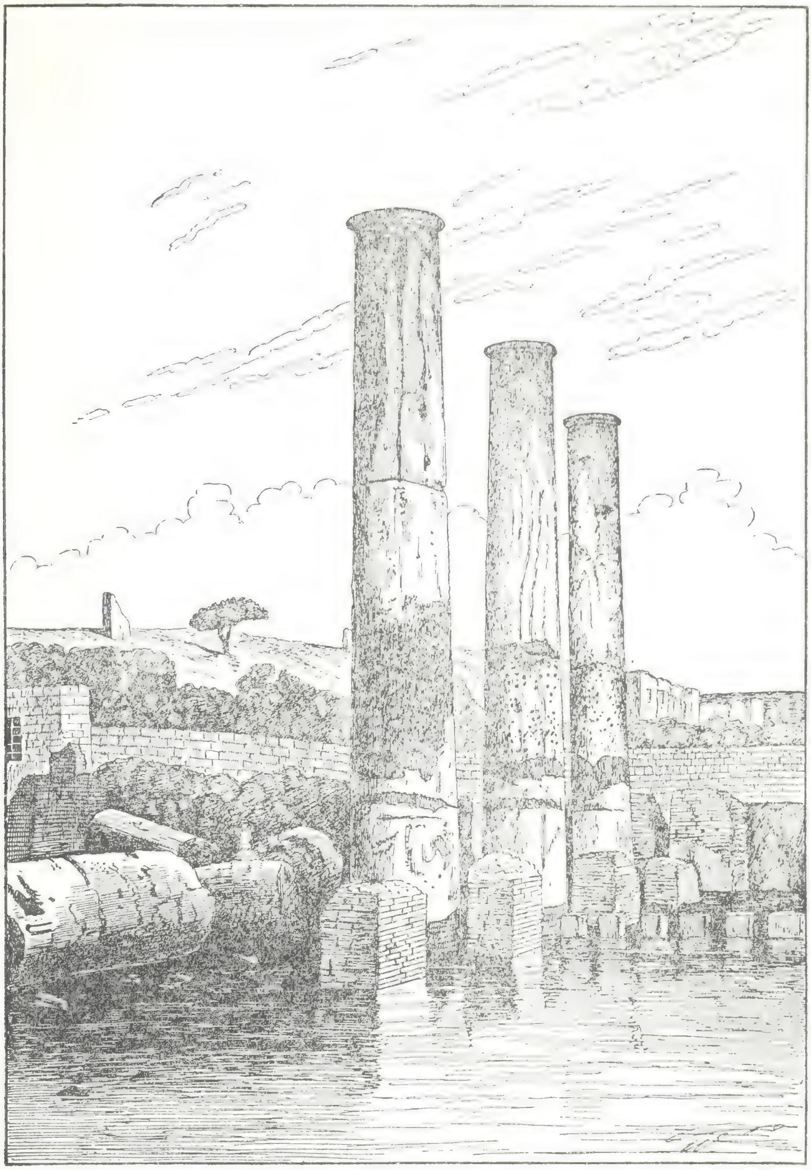
---

[1] The fact of the three standing columns having been each formed out of a single stone was first pointed out to me by Mr. James Hall, and is important as helping to explain why they were not shaken down.

On the pavement of the temple lie some columns of marble, which are also perforated in certain parts; one, for example, to the length of eight feet, while, for the length of four feet it is uninjured. Several of these broken columns are eaten into, not only on the exterior, but on the cross fracture, and, on some of them, other marine animals have fixed themselves. All the granite pillars are untouched by lithodomi. The platform of the temple, which is not perfectly even, was, when I visited it in 1828, about one foot below high-water mark (for there are small tides in the bay of Naples); and the sea, which was only one hundred feet distant, soaked through the intervening soil. The upper part of the perforations, therefore, were at least twenty-three feet above high-water mark; and it is clear that the columns must have continued for a long time in an erect position, immersed in salt water, and then the submerged portion must have been upraised to the height of about twenty-three feet above the level of the sea.

By excavations carried on in 1828, below the marble pavement on which the columns stand, another costly pavement of mosaic was found, at the depth of about five feet below the upper one. The existence of these two pavements at different levels, clearly implies some subsidence previously to the building of the more modern temple which had rendered it necessary to construct the new floor at a higher level.

We have already seen that a temple of Serapis existed long before the Christian era. The change of level just mentioned



(After Lyell.)

FIG. 10.—VIEW OF THE TEMPLE OF SERAPIS AT PUZZUOLI IN 1836.

must have taken place some time before the end of the second century, for inscriptions have been found in the temple, from which we learn that Septimius Severus adorned its walls with precious marbles, between the years 194 and 211 of our era, and the emperor Alexander Severus displayed the like munificence between the years 222 and 235. From that era there is an entire dearth of historical information for a period of more than twelve centuries, except the significant fact that Alaric and his Goths sacked Puzzuoli in 456, and that Genseric did the like in 545, A.D. Yet we have fortunately a series of natural archives self-registered during the dark ages, by which many events which occurred in and about the temple are revealed to us. These natural records consist partly of deposits, which envelop the pillars below the zone of lithodomous perforations, and partly of those which surround the outer walls of the temple. Mr. Babbage, after a minute examination of these, has shown that incrustations on the walls of the exterior chambers and on the floor of the building demonstrate that the pavement did not sink down suddenly, but was depressed by a gradual movement. The sea first entered the court or atrium and mingled its waters partially with those of the hot spring. From this brackish medium a dark calcareous precipitate was thrown down, which became, in the course of time, more than two feet thick; including some serpulæ in it. The presence of these annelids teaches us that the water was salt or brackish. After this period the temple was filled up with an irregular mass of volcanic tuff, probably derived from an eruption of the neighboring crater of the Solfatara, to the height of from five to nine feet above the pavement. Over this again a purely freshwater deposit of carbonate of lime accumulated with an uneven bottom since it necessarily accommodated itself to the irregular outline of the upper surface of the volcanic shower before thrown down. The top of the same deposit (a freshwater limestone) was perfectly even and flat, bespeaking an ancient water level. It is suggested by Mr. Babbage that this freshwater lake may have been caused by the fall of ashes which choked up the channel previously communicating with the sea, so that the hot spring threw down calcareous matter in the atrium, without any marine intermixture. To the fresh-water limestone succeeded another irregular mass of volcanic ashes and rubbish, some of it perhaps washed in by the waves of the sea during a storm, its surface rising to ten or eleven feet above the pavement. And thus we arrive at the period of greatest depression when the lower half of the pillars were enveloped in the deposits above enumerated, and the uppermost twenty feet were exposed in the atmosphere, the remaining or middle portion, about nine feet long, being for years immersed in salt water and drilled by perforating bivalves.[1] After this period other strata, consisting of showers of volcanic ashes and materials washed in during storms, covered up the pillars to the height in some places of thirty-five feet above the pavement. The exact time when these enveloping masses were heaped up, and how much of them were formed during submergence, and how much after the re-elevation of the temple, cannot be made out with certainty.

The period of deep submergence was certainly antecedent to the close of the fifteenth century. Professor James Forbes has reminded us of a passage in an old Italian writer Loffredo, who says that in 1530, or fifty years before he wrote, which was in 1580, the sea washed the base of the hills which rise from the flat land called La Starza, so that, to quote his words, "a person might then have fished from the site of those ruins which are now called the Stadium."

But we know from other evidence that the upward movement had begun before 1530, for the Canonico Andrea di Jorio cites two authentic documents in illustration of this point. The first, dated Oct. 1503, is a deed written in Italian by which Ferdinand and Isabella grant to the University of Puzzuoli a portion of land, "where the sea is drying up"; the second, a document in Latin, dated May 23, 1511, or nearly eight years after, by which Ferdinand grants to the city a certain territory around Puzzuoli, where the ground is dried up from the sea (desiccatum).

---

[1] *Lithodomus.*—Ed. Note.

The principal elevation, however, of the low tract unquestionably took place at the time of the great eruption of Monte Nuovo in 1538. That event and the earthquakes which preceded it have been already described; and we have seen that two of the eye witnesses of the convulsion, Falconi and Giacomo di Toledo, agree in declaring that the sea abandoned a considerable tract of the shore, so that fish were taken by the inhabitants; and, among other things, Falconi mentions that he saw two springs *in the newly discovered ruins.*

The flat land when first upraised, must have been more extensive than now, for the sea encroaches somewhat rapidly, both to the north and southeast of Puzzuoli. The coast had, when I examined it in 1828, given way more than a foot in a twelvemonth; and I was assured, by fishermen in the bay, that it had lost ground near Puzzuoli, to the extent of thirty feet, within their memory.

It is, moreover, very probable that the land rose to a greater height at first before it ceased to move upwards, than the level at which it was observed to stand when the temple was rediscovered in 1749, for we learn from a memoir of Niccolini, published in 1838, that since the beginning of the nineteenth century, the temple of Serapis has subsided more than two feet. That learned architect visited the ruins frequently, for the sake of making drawings, in the beginning of the year 1807, and was in the habit of remaining there throughout the day, yet never saw the pavement overflowed by the sea, except occasionally when the south wind blew violently. On his return, sixteen years after, to superintend some excavations ordered by the king of Naples, he found the pavement covered by sea-water twice every day at high tide, so that he was obliged to place there a line of stones to stand upon. This induced him to make a series of observations from October 1822 to July 1838, by which means he ascertained that the ground had been and was sinking, at the average rate of about seven millimetres a year, or about one inch in four years; so that in 1838, fish were caught every day on that part of the pavement where, in 1807, there was never a drop of water in calm weather.

The inhabitants of Scandinavia are being lifted continuously, though insensibly, to a higher altitude. No disastrous earthquakes apprise them of the movement; but continued observations on the coasts of the Baltic Sea have established not only the fact of slow uplift but also the rate, which varies from place to place. A hundred years ago the inhabitants of that region had worked out this problem to their satisfaction; but as the facts had never been stated fully and convincingly, Lyell doubted the reports. In 1834 he visited the Baltic to make an independent study, and saw that there was no escape from accepting the clear evidence of emergence on a large scale. Moreover Lyell, with his keen faculty of observation, recorded much new evidence on the problem; and his clear exposition of the facts dispelled all doubts among scientists. Part of his account (1860, pp. 523-529) is given below:

> In the year 1807, Von Buch, after returning from a tour in Scandinavia, announced his conviction, "that the whole country, from Frederickshall in Norway to Abo in Finland, and perhaps as far as St. Petersburgh, was slowly and insensibly rising." He also suggested "that Sweden may rise more than Norway, and the northern more than the southern part." He was led to these conclusions principally by information obtained from the inhabitants and pilots, and in part by the occurrence of marine shells of recent species, which he had found at several points on the coast of Norway above the level of the sea. He also mentions the marks set on the rocks. Von Buch, therefore, has the merit of being the first geologist who, after a personal examination of the evidence, declared in favor of the rise in land in Scandinavia.
>
> The attention excited by this subject in the early part of the last century, induced many philosophers in Sweden to endeavor to determine, by accurate observations, whether the standard

level of the Baltic was really subject to periodical variations; and under their direction, lines or grooves, indicating the ordinary level of the water on a calm day, together with the date of the year, were chiselled out upon the rocks. In 1820-21, all the marks made before those years were examined by the officers of the pilotage establishment of Sweden; and in their report to the Royal Academy of Stockholm they declared, that on comparing the level of the sea at the time of their observations with that indicated by the ancient marks, they found that the Baltic was lower relatively to the land in certain places, but the amount of change during equal periods of time had not been everywhere the same. During their survey, they cut new marks for the guidance of future observers, several of which I had an opportunity of examining fourteen years after (in the summer of 1834), and in that interval the land appeared to me to have risen at certain places north of Stockholm, four or five inches. I also convinced myself, during my visit to Sweden, after conversing with many civil engineers, pilots, and fishermen, and after examining some of the ancient marks, that the evidence formerly adduced in favor of the change of level, both on the coasts of Sweden and Finland, was full and satisfactory. The alteration of level evidently diminishes as we proceed from the northern parts of the Gulf of Bothnia towards the south, being very slight around Stockholm. Some writers have indeed represented the rate of depression of the waters at Stockholm as very considerable, because certain houses in that city which are built on piles have sunk down within the memory of persons still living, so as to be out of the perpendicular; and this in consequence of the tops of the piles giving way and decaying, owing to a fall of the waters which has exposed them to be alternately wet and dry. The houses alluded to are situated on the borders of Lake Maeler, a large lake, the outlet of which joins the Baltic, in the middle of Stockholm. This lake is certainly lower than formerly; but the principal cause of the change is not the elevation of the land, but the removal of two old bridges built on piles, which formerly obstructed the discharge of the fresh water into the sea. Another cause is the opening, in the year 1819, of a new canal at Södertelje, a place south of Stockholm, by means of which a new line of communication was formed between Lake Maeler and the Baltic.

It will naturally be asked, whether the mean level of a sea like the Baltic can ever be determined so exactly as to permit us to appreciate a variation of level, amounting only to one or two feet. In reply, I may observe, that, except near the Cattegat, there are no tides in the Baltic; and it is only when particular winds have prevailed for several days in succession, or at certain seasons when there has been an unusually abundant influx of river water, or when these causes have combined, that this sea is made to rise two or three feet above its standard level. The fluctuations due to these causes are nearly the same from year to year; so that the pilots and fishermen believe and apparently with reason, that they can mark a deviation, even of a few inches, from the ordinary or mean height of the waters.

There are, moreover, peculiarities in the configuration of the shores of Norway and Sweden, which facilitate in a remarkable degree the appreciation of slight changes in the relative level of land and water. It has often been said, that there are two coasts, an inner and an outer one; the inner being the shore of the main land; the outer one, a fringe of countless rocky islands of all dimensions, called the skär. Boats and small vessels make their coasting voyages within this skär: for here they may sail in smooth water, even when the sea without is strongly agitated. But the navigation is very intricate, and the pilot must possess a perfect acquaintance with the breadth and depth of every narrow channel, and the position of innumerable sunken rocks. If on such a coast the land rises one or two feet in the course of half a century, the minute topography of the skär is entirely altered. To a stranger, indeed, who revisits it after an interval of many years, its general aspect remains the same; but the inhabitant finds that he can no longer penetrate with his boat through channels where he formerly passed, and he can tell of countless other changes in the height and breadth of isolated rocks, now exposed, but once only seen through the clear water.

The rocks of gneiss, mica-schist, and quartz are usually very hard on this coast, slow to decompose, and, when protected from the breakers, remaining for ages unaltered in their form. Hence it is easy to mark the stages of their progressive emergence by the aid of natural and artificial marks imprinted on them. Besides the summits of *fixed* rocks, there are numerous erratic blocks of vast size strewed over the shoals and islands in the skär, which have been probably drifted by ice. All these are observed to have increased in height and dimension with the last half century. Some, which were formerly known as dangerous sunken rocks, are now only hidden when the water is highest. On their first appearance, they usually present a smooth, bare, rounded protuberance, a few feet or yards in diameter; and a single sea-gull often appropriates to itself this resting-place, resorting there to devour its prey. Similar points, in the meantime, have grown to long reefs, and are constantly whitened by a multitude of sea-fowl; while others have been changed from a reef, annually submerged, to a small islet, on which a few lichens, a fir-seedling, and a few blades of grass, attest that the shoal has at length been fairly changed into dry land. Thousands of wooded islands around show the great alterations which time can work. In the course of centuries also, the spaces intervening between the existing islands may be laid dry, and become grassy plains encircled by heights well clothed with lofty firs. This last step of the process, by which long fiords and narrow channels, once separating wooded islands, are deserted by the sea, has been exemplified within the memory of living witnesses on several parts of the coast.

The town of Uddevalla stands at the head of a narrow creek overhung by steep and barren rocks of gneiss, of which all the adjacent country is composed, except in the low grounds and bottoms of valleys, where strata of sand, clay, and marl frequently hide the fundamental rocks. To these newer and horizontal deposits the fossil shells above mentioned belong, and similar marine remains are found at various heights above the sea on the opposite island of Orust. The extreme distance from the sea to which such fossils extend is as yet unknown; but they have been already found at Trollhättan in digging the canal there, and still farther inland on the northern borders of Lake Wener, fifty miles from the sea, at an elevation of 200 feet near Lake Rogvarpen.

To pass to the Baltic: I observed near its shores at Södertelje, sixteen miles S.W. of Stockholm, strata of sand, clay, and marl, more than 100 feet high, and containing shells of species now inhabiting the Bothnian Gulf. These consist partly of marine and partly of fresh-water species; but they are few in number, the brackishness of the water appearing to be very unfavorable to the development of testacea. The most abundant species are the common cockle and the common mussel and periwinkle of our shores, together with a small tellina and a few minute univalves. These live in the same water as a *Lymneus,* a *Neritina,* and some other fresh-water shells.

But the marine mollusks of the Baltic above mentioned, although very numerous in individuals, are dwarfish in size, scarcely ever attaining a third of the average dimensions which they acquire in the salter waters of the ocean. By this character alone a geologist would generally be able to recognize an assemblage of Baltic fossils as distinguished from those derived from a deposit in the ocean. The absence also of oysters, barnacles, whelks, scallops, limpets, and many other forms abounding alike in the sea near Uddevalla, and in the fossiliferous deposits of modern date on that coast, supplies an additional negative character of the greatest value, distinguishing assemblages of Baltic from those of oceanic shells. Now the strata containing Baltic shells are found in many localities near Stockholm, Upsala, and Gefle, and will probably be discovered everywhere around the borders of the Bothnian Gulf; for I have seen similar remains brought from Finland, in marl resembling that found near Stockholm. The utmost distance to which these deposits have yet been traced inland, is on the southern shores of Lake Maeler, at a place seventy miles from the sea. Hence it appears from the distinct assemblage of fossil shells found on the eastern and western coasts of Sweden, that the Baltic has been for a long period separated as now from the ocean, although the intervening tract of land was once much narrower, even after both seas had become inhabited by all the existing species of testacea.

As no accurate observations on the rise of the Swedish coast refer to periods more remote than a century and a half from the present time, and as traditional information, and that derived from ancient buildings on the coast, do not enable the antiquary to trace back any monuments of change for more than five or six centuries, we cannot declare whether the rate of the upheaving force is uniform during very long periods. In those districts where the fossil shells are found at the height of more than 200 feet above the ocean, as at Uddevalla, Orust, and Lake Rogvarpen, the present rate of rise seems less than four feet in a century. Even at that rate it would have required five thousand years to lift up those deposits. But as the movement is now very different in different places, it may also have varied much in intensity at different eras.

We have, moreover, yet to learn not only whether the motion proceeds always at the same rate, but also whether it has been uniformly *in one direction*. The level of the land may oscillate; and for centuries there may be a depression, and afterwards a re-elevation, of the same district. Some phenomena in the neighborhood of Stockholm appear to me only explicable on the supposition of the alternate rising and sinking of the ground since the country was inhabited by man. In digging a canal, in 1819, at Södertelje, about sixteen miles to the south of Stockholm, to unite Lake Maeler with the Baltic, marine strata, containing fossil shells of Baltic species, were passed through. At a depth of about sixty feet, they came down upon what seems to have been a buried fishing-hut, constructed of wood in a state of decomposition, which soon crumbled away on exposure to the air. The lowest part, however, which had stood on a level with the sea, was in a more perfect state of preservation. On the floor of this hut was a rude fireplace, consisting of a ring of stones, and within this were cinders and charred wood. On the outside lay boughs of the fir, cut as with an ax, with the leaves or needles still attached. It seems very difficult to explain the position of this buried hut, without imagining, as in the case of the temple of Serapis, first a subsidence to the depth of more than sixty feet, then a re-elevation. During the period of submergence, the hut must have become covered over with gravel and shelly marl, under which not only the hut, but several vessels also were found, of very antique forms, and having their timbers fastened together by wooden pegs instead of nails.

We learn from the nature of the Scandinavian uplift that not all important movements of the Earth's crust are attended by violent earthquakes. The lands around the Baltic are not visited by disastrous shocks. Evidently the uplift is very gradual, and there is an absence of local strains which would cause the formation and repeated slipping of faults.

The upward movement of Scandinavia has been in progress during much of the 10,000 or more years since the cover of glacial ice began to disappear rapidly. There has been a bowing up of the entire peninsula, and in northern Sweden the total rise has been nearly a thousand feet.

Mountains

Earthquakes that originate beneath the surfaces of continents are most numerous in or near mountains of recent origin; and most of the shocks beneath the floor of the Pacific have their centers either near island chains, which represent partly submerged mountains, or in zones of active movement known as *foredeeps.* Many severe earthquakes are the "growing pains" of mountain ranges. Their frequent occurrence in a mountain belt indicates continued growth in height, or in complexity of structure, or both. The common association of earthquakes with faults is well known, and it is probable that the development of folds causes disturbances of equal magnitude.

The great earthquake of Yakutat Bay, described above, is believed to mark a step in the uplift of the St. Elias Range, Alaska. The Sierra Nevada of California, containing the highest peak and some of the finest mountain scenery in the United States, has been raised from a surface of low relief late in geologic time, probably by a long succession of small displacements along a fault zone. Lawson, with a few effective strokes, has drawn a generalized picture of this great range as it is seen by the geologist (1921, pp. 135-137, 139-141):

> Now, the Sierra Nevada is, in the sense just indicated, of the Basin Range type of mountains. It constitutes a vast block of the earth's crust, many times longer than broad, which has been rotated on an axis parallel with its length, so that the eastern edge, dislocated from the region of the present Great Basin, has been elevated to make the crest of the range, while the western edge has been depressed below sea-level and is buried by the deposits which underlie the floor of the Great Valley of California. This is a very simple conception of the general structure and configuration of what appeals to most mountaineers as a veritable "sea of mountains," as they view the Sierra from some of its commanding peaks. It substitutes unity for plurality, although we are still constrained to refer to the range in the plural. The unit in this case is large, even as mountains go, and the Sierra Nevada may be regarded as the largest as well as the finest example of simple tilted blocks of the Basin Range type, so far as our authentic information at present indicates.
>
> The bewildering "sea of mountains" which one looks down upon from the peaks of the high Sierra is the result of the sculpture of this great block. The disintegrating action of the atmosphere, the stress of gravity, the transporting action of

running water, the corrasive action of the load of rock debris as it moves forward in the streams, the corrading, sapping, and transporting action of glaciers—these have all conspired to carve out of the Sierran block the magnificent features which we designate, collectively, the mountains. Ever since the inauguration of its uplift, the mountain mass has been subject to the ceaseless attack of some or all of these degrading forces. They have evolved the profound canyons which dissect it and out through these canyons there has been swept probably half the original volume of the tilted block. We might picture to ourselves the original form of the block, in its simplest outline, by imagining these great canyons filled up to the level of the great ridges which divide them one from another. The picture thus formed, however, by the effort of the imagination, is not a true picture of the mountain at any stage of its evolution; it is rather an outline of the tilted block as it would be to-day had it never been affected by the degrading forces of erosion. But these forces have been at work since the very inception of the elevatory movement. This movement has been a slow and intermittent one, so that the dissection of the block and the general degradation of its surface have proceeded hand in hand with its gradual uplift. From these considerations it appears that the conception of the Sierra Nevada as a tilted block of the earth's crust of simple asymmetric profile, is one which has never been realized in fact. The abstraction which the geologist makes use of for the purpose of determining the type of mountain is confined to the result of the formative process and ignores the degradational process. But while we can thus think clearly of the one process independently of the other, in reality the product of the formative uplift has never for a moment been unmodified by the process which makes for obliteration. . . .

. . . Although the range has been degraded to nearly one-half its original volume, and although the corrasion of the vast canyons by the streams must have taken a very long period of time, measured in years or centuries, yet, from a comparative point of view, the Sierra Nevada may be safely placed among the young and giddy mountains of our planet.

This conclusion is confirmed by a consideration of the eastern front of the range overlooking the Great Basin. This, as has been stated, is a somewhat degraded fault scarp, originally the exposed side of the block along the plane of its dislocation from the country to the east. The scarp, under the disintegrating action of the atmosphere, has been undergoing a slow recession ever since its emergence. This disintegration is probably promoted by gravitational stresses within the mass, which find relief on uplift in the disruption of the rocky mass along systems of intersecting parting planes known as joints. The blocks bounded by these joints are readily dislodged by the heaving action of frost, and innumerable such blocks have been shed from the face of the fault scarp, thus effecting its gradual recession. Owing to the greater rapidity with which this process proceeds in the upper portion of the scarp, and the protection afforded to the lower portion by the accumulating talus of fragments that fall from above, the tendency is to reduce the original declivity to a more moderate slope. In a geological sense this degradation of the originally steep face of the scarp is a rapid process. Yet how little has it accomplished! To stand on the brink of Mt. Whitney, to view the great Sierran wall to the north, to the south, to gaze down into Owen's Valley over two miles below, to look out over the vast expanse of "the land of little rain" as from a balloon, to stand there is to drink in one of the most impressive lessons in American geology—and that lesson is the recency of the upheaval of the Sierran block. The great wall has suffered but little from the vigorous and incessant onslaught of the forces of degradation. It is still a wall. Even along those lines of maximum intensity of the erosive process, the stream courses, the results are small. The steep grade of these easterly streams suggests that they should in time have cut through the general line of the crest and thrown the divide far to the west of it. The erosive power of streams is a function of their grade, and it is a well established principle in geology that if the streams on two sides of a mountain ridge be of unequal grade the steeper will have the advantage, and, other things being equal, will cut their canyons back into the ridge faster than those flowing down the gentler slope, and thus bring about a gradual migration of the divide down the gentler slope till equilibrium be established. This migration of the divide between the east and the west flowing streams in the Sierra Nevada has made but little progress. . . . The fact that the divide so nearly coincides with the brink of the range is an additional proof of the youthfulness of the Sierra Nevada.

BIBLIOGRAPHY

Chapter X—Movements of the Earth's Crust

Clarence E. Dutton, *The Charleston Earthquake of August 31, 1886.* U. S. Geological Survey, Ninth Annual Report, 1887-1888, pp. 212-219, 240, 265-267, 274-275, 334, 335, 341-342, 346.

Myron E. Fuller, *The New Madrid Earthquake.* U. S. Geological Survey, Bulletin 494, 1912, pp. 10-11, 102-105.

N. H. Heck, *Earthquake History of the United States.* U. S. Coast and Geodetic Survey, Special publication No. 149, 1928, pp. 38-41.

Andrew C. Lawson, *The Sierra Nevada.* University of California Chronicle, April, 1921, pp. 135-137, 139-141.

Sir Charles Lyell, *Principles of Geology.* Ninth Ed., New York: Appleton, 1860, pp. 457-460, 511-516, 523-529.

Ralph S. Tarr and Lawrence Martin, *The Earthquakes at Yakutat Bay, Alaska.* U. S. Geological Survey, Professional Paper 69, 1912, pp. 11, 22, 31, 79.

E. W. Webster, *The Works of Aristotle.* English translation, 1923, Book II, pp. 7, 365a.

CHAPTER XI

METAMORPHISM

What geologist has not sometime wished that the rocks over which he walked would dissolve into mist as did the looking-glass through which Alice passed to her strange adventures? Then he would slip down through the overburden of unaltered rock to those masses that are being reconstituted by heat and pressure and engulfed by molten matter from below. He would see metamorphic rocks as they are made and perhaps understand at a glance some of the problems that have harassed geologists since man first tried to place the strata of the Earth in an orderly array. But even though he cannot pass down thus into the workshops of Nature, he can examine the results, uncovered at last by age-long erosion, in the ancient nuclei of the continents and the cores of old and recent mountain ranges.

The rocks he sees there belong to a class apart. Their original condition as sedimentary or igneous rocks may or may not be apparent, but they have been recrystallized and their minerals are usually drawn out into bands. They are the foliated crystalline schists and gneisses or the more massive marbles and quartzites. Many of them are penetrated by numberless veins and dikes of granite and pegmatite so that even their schistosity, newly acquired, is locally obliterated.

Close study of the structures and textures of these rocks and of the mineralogical and chemical changes that they have undergone, has taught us much about how they are made. We have clear proof, for instance, that they are reconstructed from pre-existing rocks belonging to all but the most recent periods, and were not deposited all at one time in the condition in which we now see them.

But the old view was different. It was believed that they were all formed just as they are today at the beginning of time and under conditions essentially different from any that obtained at a later date.

We will review the older ideas because, though they have been tested in the light of increased knowledge and rejected, they form the foundation upon which our modern conception has grown. We have advanced from those views, but they can still teach us much. They represent the first gropings after an explanation for very complex phenomena, and we must not forget that our views as well will be "old" some day. Sir Henry T. de la Beche says (1851, Preface):

> It has been well remarked by Humboldt,[1] that to behold is not necessarily to observe, that is, to compare and combine. The history of Geology, like that of all sciences depending for their effective advance on experiment or correct observation, amply proves the truth of this statement. We are not required to look far back to be fully aware of the many brilliant hypotheses which have given way before the advance of correct research. It was not that these brilliant hypotheses were intended as substitutes for sound geological knowledge, based on correct data, or that those who formed them were not as capable as any who may in after-times succeed in still farther systematically embodying the accumulated data of such times, but merely that correct observations were not then sufficiently abundant, and that powerful, and, sometimes, impatient minds often supplied their place with conceptions more captivating than well founded. It is obvious that with a hundred well-established facts more can be accomplished than with ten, the deductions from which, however apparently correct, may even be fallacious as respects those derived from the consideration of the greater number. Let it not, nevertheless, be hastily concluded that the views which have passed away have not materially advanced Geology, as those of a similar character have aided the progress of other sciences. Without them, though a few may have been impediments for the time, many a subject would have longer remained disregarded by its zealous investigator.

---

[1] Kosmos.

The Old Classification of Rocks

Lyell (1855, pp. 90-92) gave a clear account of the early classification of rocks and the ideas concerning metamorphism. He wrote:

> It was for many years a received opinion that the formation of entire families of rocks, such as the plutonic and those crystalline schists spoken of . . . as metamorphic, began and ended before any members of the aqueous and volcanic orders were produced; and although this idea has long been modified, and is nearly exploded, it will be necessary to give some account of the ancient doctrine in order that beginners may understand whence many prevailing opinions, and some part of the nomenclature of geology, still partially in use, was derived.
>
> About the middle of the last century, Lehman, a German miner, proposed to divide rocks into three classes, the first and oldest to be called primitive, comprising the hypogene, or plutonic and metamorphic rocks; the next to be termed secondary, comprehending the aqueous or fossiliferous strata; and the remainder, or third class, corresponding to our alluvium, ancient and modern, which he referred to "local floods, and the deluge of Noah." In the primitive class, he said, such as granite and gneiss, there are no organic remains, nor any signs of materials derived from the ruins of pre-existing rocks. Their origin, therefore, may have been purely chemical, antecedent of the creation of living beings, and probably coeval with the birth of the world itself. The secondary formations, on the contrary, which often contain sand, pebbles, and organic remains, must have been mechanical deposits, produced after the planet had become the habitation of animals and plants. This bold generalization, although anticipated in some measure by Steno, a century before, in Italy, formed at the time an important step in the progress of geology, and sketched out correctly some of the leading divisions into which rocks may be separated. About half a century later, Werner, so justly celebrated for his improved methods of discriminating the

mineralogical characters of rocks, attempted to improve Lehman's classification, and with this view intercalated a class, called by him "the transition formations," between the primitive and secondary. Between these last he had discovered, in northern Germany, a series of strata, which in their mineral peculiarities were of an intermediate character, partaking in some degree of the crystalline nature of micaceous schist and clay-slate, and yet exhibiting here and there signs of a mechanical origin and organic remains. For this group, therefore, forming a passage between Lehman's primitive and secondary rocks, the name of transition was proposed. They consisted principally of clay-slate and an argillaceous sandstone called grauwacke and partly of calcareous beds. It happened in the district which Werner first investigated, that both the primitive and transition strata were highly inclined, while the beds of the newer and fossiliferous rocks, the secondary of Lehman, were horizontal. To these latter, therefore, he gave the name of *flötz,* or "a level floor;" and every deposit more modern than the chalk, which was classed as the uppermost of the flötz series, was designated "the overflowed land," an expression which may be regarded as equivalent to alluvium, although under this appellation were confounded all the strata afterwards called tertiary, of which Werner had scarcely any knowledge. As the followers of Werner soon discovered that the inclined position of the "transition beds," and the horizontality of the flötz, or newer fossiliferous strata, were mere local accidents, they soon abandoned the term flötz; and the four divisions of the Wernerian school were then named primitive, transition, secondary, and alluvial.

As to the trappean rocks, although their igneous origin had been already demonstrated . . . they were all regarded by Werner as aqueous, and as mere subordinate members of the secondary series.

This theory of Werner's was called the "Neptunian," and for many years enjoyed much popularity. It assumed that the globe had been at first invested by an universal chaotic ocean, holding the materials of all rocks in solution. From the waters of this ocean, granite, gneiss, and other crystalline formations, were first precipitated; and afterwards, when the waters were purged of these ingredients, and more nearly resembled those of our actual seas, the transition strata were deposited. These were of a mixed character, not purely chemical, because the waves and currents had already begun to wear down solid land, and to give rise to pebbles, sand, and mud; nor entirely without fossils, because a few of the first marine animals had begun to exist. After this period, the secondary formations were accumulated in waters resembling those of the present ocean, except at certain intervals, when, from causes wholly unexplained, a partial recurrence of the "chaotic fluid" took place, during which various trap rocks, some highly crystalline, were formed. This arbitrary hypothesis rejected all intervention of igneous agency, volcanos being regarded as modern, partial, and superficial accidents, of trifling account among the great causes which have modified the external structure of the globe.

Meanwhile Hutton, a contemporary of Werner, began to teach, in Scotland, that granite as well as trap was of igneous origin, and had at various periods intruded itself in a fluid state into different parts of the earth's crust. He recognized and faithfully described many of the phenomena of granitic veins, and the alterations produced by them on the invaded strata . . . He, moreover, advanced the opinion, that the crystalline strata called primitive had not been precipitated from a primeval ocean, but were sedimentary strata altered by heat. . . .

It must be borne in mind that Lehman, writing in the middle of the eighteenth century, did not possess the terms "plutonic" or "metamorphic," nor the concept which those terms expressed to Lyell. Lyell inserted them to show what, in his terminology, Lehman's primitive system included.

The conception that the metamorphic rocks of the Earth's crust, as well as basalt and granite, were all precipitated out of a universal ocean in the beginning of time was simple enough and easily visualized. It appealed strongly to the orderly mind of Werner who, by the weight of his personal authority and by a charm that made all who came in contact with him his enthusiastic supporters, forced this theory upon much of the scientific world. But the generalization was based upon the investigation of a very small area and upon the wrong interpretation of the facts there revealed, so that, in spite of the often blind adherence of Werner's disciples, the "neptunian" theory soon tottered and fell, leaving as its legacy an increased interest in geology and a growing desire to "go and see" instead of weaving theories based upon very little observation.

Hutton's Views

The Scottish geologist Hutton combated Werner's views from the start. He proved the igneous origin of granite and basalt and showed that they intruded the schists of Scotland and the Alps. The following extract from Sir Archibald Geikie (1905, pp. 310-311), which includes a passage from Hutton's own writings, makes this clear:

> In the Huttonian theory we find the germ of the Lyellian doctrine of metamorphism. Hutton, having demonstrated that granite is not an aqueous but an igneous rock, further showed that the "Alpine schistus," (which included sandstones, shales and slates, as well as crystalline schists), being stratified, could not be original or primitive, but had been deposited like recent sediments, and had been invaded and altered by the granite. A passage from his chapter, "On the Primary Part of the Present Earth" may be quoted in illustration of the sagacity of his judgment on this subject: "If, in examining our land, we shall find a mass of matter which had been evidently formed originally in the ordinary manner of stratification, but which is now extremely distorted in its structure and displaced in its position,—which is also extremely consolidated in its mass and variously changed in its composition,—which, therefore, has the marks of its original or marine composition extremely obliterated, and many subsequent veins of melted mineral matter interjected, we should then have reason to suppose that

here were masses of matter which, though not different in their origin from those that are gradually deposited at the bottom of the ocean, have been more acted upon by subterranean heat and the expanding power, that is to say, have been changed in a greater degree by the operations of the mineral kingdom."[1]

Hutton here compresses into a single, though somewhat cumbrous, sentence the doctrine to which Lyell in later years gave the name metamorphism.

Hutton's ideas finally prevailed, and when Lyell wrote his classical works on geology during the first half of the Nineteenth Century he recognized the distinction between the igneous rocks and the gneisses and schists. It was in 1833 that Lyell (p. 375) first proposed the term "metamorphic" (from meta—trans, and morphos—form) to distinguish the "altered stratified" rocks, the schists and gneisses, and to show, in their very name, the conception that they were changed after their original formation.

The Age of Metamorphic Rocks

Lyell (1872, pp. 140-142) also recognized that these metamorphic strata had not all been formed at one time and set to work to prove that they were formed in equal amounts during all periods:

> So also if stratified rocks are now by hydrothermal action, or under the influence of intensely heated steam and other gases, undergoing semi-fusion and reconstruction far underground, it will probably require the lapse of many periods before they will be forced up to the surface and exposed to view by denudation, even at a single point. To effect this purpose there may be need of as great a development of subterranean movement as that which in the Alps, Andes, and Himalayas has raised strata containing marine fossil shells and ammonites to the height of 8,000, 14,000, and 16,000 feet. By parity of reasoning we can hardly expect that any tertiary rocks of the hypogene class will have been brought within the reach of human observa-

---

[1] *Theory of the Earth,* vol 1, pp. 375, 376. This passage may serve also as an illustration of Hutton's peculiar style of composition.

tion, save at a few isolated points, seeing that the emergence of such rocks must always be so long posterior to the date of their origin; and, as extensive denudation must also combine with upheaval before they can be displayed at the surface throughout wide areas, formations of this class cannot become generally visible until so much time has elapsed as to confer on them a high relative antiquity.

All geologists who reflect on subterranean movements now going on, and the eruptions of active volcanoes, are convinced that great changes are now continually in progress in the interior of the earth's crust far out of sight. They must be conscious, therefore, that the inaccessibility of the regions in which these alterations are taking place compels them to remain in ignorance of a great part of the working of existing causes, so that they can only form vague conjectures in regard to the nature of the products which volcanic heat, aided by steam and various gases, may elaborate under great pressure.

When therefore they find in mountain-chains of high antiquity, that what was once the interior of the earth's crust has since been forced outwards by mechanical violence or exposed to view by denudation, they may expect to behold some of the nether formed rocks of remote eras, the modern representatives of which they cannot see. They may be prepared to find that these rocks will differ wholly from the fossiliferous strata deposited at the surface and from the lava and scoria thrown out by modern volcanoes in the open air. They may recognize in granite, gneiss, mica-schist, hornblende schist, and other crystalline rocks, products of a nature and aspect distinct from those which they have observed in process of formation, and these they may therefore be ready to refer to the action of subterranean heat and gases under great pressure.

. . . The anomalous appearances are the result, not of an order of things which has passed away, but of a set of conditions removed by their very nature from the possibility of being observed. They are not the monuments of the primeval period, bearing inscribed upon them in obsolete characters the words and phrases of a dead language; but they teach us that part of the living language of nature which we cannot learn by our daily intercourse with what passes on the habitable surface.

The Modern View

According to this view an examination of the average metamorphic rock exposed on the surface to-day, recrystallized, crushed, and twisted by the forces that brought it into being, shows us what is surely happening to other rocks somewhere beneath our feet at the present time. It allows us to read in the contortions of a rock and the minerals that compose it the forces that developed it, instead of relegating all such strata to the unknown, nascent period of the Earth.

After this view took a firm hold the study of metamorphism made great advances. One school of thought regarded all the changes that occur as due to the heat inherent in the depths of the Earth, to pressure and to the moisture always present in a rock. Another view held that magmas and the gaseous emanations arising from them are the more potent cause of recrystallization. This was strengthened by the known effect of igneous rocks upon the strata which they intrude.

These contrary views have persisted to the present day though they are now fairly united in any general theory of metamorphism. We see the effect of pressure in the crushing and granulation of rocks and many believe it capable of causing the recrystallization of the materials of a rock when enough heat and moisture are present; but we also recognize, in some of the banded gneisses, the result of magmatic injection over large areas. In such cases, the magmas have penetrated the older rocks in regular or irregular bands so as to give composite metamorphic rocks that are mixtures of sedimentary and igneous types.

Some time elapsed, however, after the sedimentary origin of many metamorphic rocks was generally admitted, before igneous rocks were known to be capable of undergoing very similar changes. Only when the microscope came to the aid of the petrographer could the gradual transition of certain igneous rocks into foliated metamorphic rocks be proved.

BIBLIOGRAPHY

Chapter XI—Metamorphism

Sir Henry T. de la Beche, *The Geological Observer.* Philadelphia: Blanchard & Lea, 1851, Preface.

Sir Archibald Geikie, *The Founders of Geology.* London: Macmillan & Company, 1905, pp. 310-311.

Sir Charles Lyell, *Principles of Geology,* London: John Murray. 1st Ed., 1833, p. 375; 11th Ed., 1872, vol. I, pp. 140-142.

—— *Elements of Geology,* London: John Murray, 1855, pp. 90-92.

CHAPTER XII

LAND FORMS

Early Perceptions of the Sculpturing Processes

Modern geologists understand that any assemblage of land forms is merely the remnant of a block of the Earth's crust that has been uplifted, and sculptured by the processes of erosion. They know further that the shapes of these sculptured blocks depend on three factors, and only three: the nature of the rock materials and the distance through which they have been uplifted, the process by which they are being sculptured, and the relative amount of time throughout which the sculpturing has been going on. Alter any one of these factors and the resulting land forms change. On them and on the attendant vegetation depends the diversity of the landscapes of the Earth.

We are accustomed to thinking of this conception as a modern idea. As a matter of common knowledge, it is modern. But its essentials are so true, and so apparent to the thinking investigator, that it was perceived long ago. The difficulty was that those who perceived it were mere voices crying in the wilderness. Consider the writings of Georg Landmann, who lived in a Saxony emerging from feudalism and who, as a scholar, translated his name into Latin and called himself Georgius Agricola. He was curious about the Earth, its rocks and its minerals. It was he who raised mineralogy to the dignity of a science. But we are interested in him chiefly for certain passages that occur in his treatise *De Re Metallica* (Hoover, 1912, pp. 595-596) which appeared in 1695. For example:

> Hills and mountains are produced by two forces, one of which is the power of water, and the other the strength of the wind. There are three forces which loosen and demolish the mountains, for in this case, to the power of the water and the strength of the wind we must add the fire in the interior of the

earth. Now we can plainly see that a great abundance of water produces mountains, for the torrents first of all wash out the soft earth, next carry away the harder earth, and then roll down the rocks, and thus in a few years they excavate the plains or slopes to a considerable depth; this may be noticed in mountainous regions even by unskilled observers. By such excavation to a great depth through many ages, there rises an immense eminence on each side. When an eminence has thus arisen, the earth rolls down, loosened by constant rain and split away by frost, and the rocks, unless they are exceedingly firm, since their seams are similarly softened by the damp, roll down into the excavations below. This continues until the steep eminence is changed into a slope. Each side of the excavation is said to be a mountain, just as the bottom is called a valley. Moreover, streams, and to a far greater extent rivers, effect the same results by their rushing and washing; for this reason they are frequently seen flowing either between very high mountains which they have created, or close by the shore which borders them. . . . Nor did the hollow places which now contain the seas all formerly exist, nor yet the mountains which check and break their advance, but in many parts there was a level plain, until the force of winds let loose upon it a tumultuous sea and a scathing tide. By a similar process the impact of water entirely overthrows and flattens out hills and mountains. But these changes of local conditions, numerous and important as they are, are not noticed by the common people to be taking place at the very moment when they are happening, because, through their antiquity, the time, place, and manner in which they began is far prior to human memory.

Illustrations of the Cycle of Erosion

The *cycle of erosion,* which is a concrete expression of the systematic treatment of land forms, has as its great exponent Professor W. M. Davis. The importance of realizing that any one landscape is merely a passing phase in a continuously changing series of forms all belonging to a single cycle of erosion is so great that although the cycle has been discussed in Chapter III, it has its place here as well. When the cycle was still a new idea, Davis (1889, pp. 570-574) wrote this argument:

> The so-called "valley" of the Red River of the North i Minnesota and Dakota is a broad plain of exceedingly leve surface. It is so truly level that it illustrates the curvature of the earth in the same way that it is seen at sea; for in crossing the plain, first a distant tree-top is seen above the horizon, then a housetop, and at last the body of the house rises into full view, just as the upper and lower sails and the hull of the ship are brought into sight in sailing toward it on the ocean. This broad plain is a lake bottom, whence the water in which its fine sediments were laid down has been drained away, and drained away by so curious a process that if, in teaching modern history, it were noted that some existing form of government were as curiously related to the past, no teacher would hesitate to make reference to it. The northern barrier that held the waters of the lake was the southward front slope of a great sheet of ice that for a time obstructed the open northward drainage; and in the lake thus created, fine sediments were spread out so plentifully that they buried the former surface of the land, and so evenly that when the waters were drained away as the ice melted, a dead-level plain was revealed.
>
> The plain stands well above sea-level, and hence must suffer change as destructive processes attack it. Why, then, is it so smooth? Manifestly because it is young. There has not yet been time for streams to channel it. It is extremely immature, truly infantile in its appearance, with scarcely a sign of the variety of features that will be developed in its later history. . . .
>
> The Red river plain has, however, begun its development. The Red river itself has incised a narrow, steep-sided trench twenty or forty feet deep in the surface of the plain, and the few side branches of the river have narrower and shallower

channels. These trenches and channels are simply young valleys, and they are growing so rapidly that their increase in length and width is noticeable even in the past few years of settlement. But still the streams have barely made a beginning of the great work of carrying away all the material of the plain above base-level, this being their manifest future task. So little has been done as yet in the way of preparing drainage channels that the rain which falls here is greatly delayed in reaching a stream course by which it may flow to its goal, the sea, and so much of it stands about idly, instead of quickly running off, that it is in good part evaporated and carried away through the air. Evidently we have here to do with a geographical individual that is just entering its career, that still retains its embryonic characteristics, so little has it advanced in its life history.

Can we not foretell something of the future history of this plain? As the rivers carve their trenches deeper and deeper, and the inclosing slopes are wasted away and widen out, and the little side gullies eat backwards and increase in length till they become ravines and the ravines grow into valleys, then the inter-stream surface, at first smooth and unbroken, is traversed in all directions by branching water courses; the rainfall is much more quickly led into the streams—everything marks a more advanced stage. But we cannot only predict the future of the Red river plains: we can find examples of other plains, born at an earlier time, that are now in the advanced stage that the Red river plains have yet to reach. Look at the coastal plains of the Carolinas. They are the old bottom of the Atlantic, laid bare by a relative uplift of the continent. They are well drained; many streams run across them, and many branches give ready discharge to the rainfall; the channels are deeper below the general level of the country than are those of the Red river plains, and the interstream surface is much more broken, yet still enough of it remains to make it clear that the present form is developed from an originally level, unbroken plain; and a close comparison will leave no doubt that the coastal plains of the Carolinas differ from the Red river plains chiefly in being further advanced in their cycle of development. They are closely related individuals, but they differ somewhat in age. They are like the egg of a caterpillar and the caterpillar itself—not very similar at first, and not like what they will come to be later on, but closely comparable for all that; their differences only manifest their relationship; what one is, the other will be; what the other is, the first has been. Thus we can introduce into geography the element of growth, that is, systematic change, and greatly to the enlivenment of the study. It is often the reproach of geography that it does not deal with things having life, but this is true only if we do not take heed of the kind of life that it may consider. One may say that the changes here discussed are so slow that we need not take account of them, but this is predetermining what we shall and what we shall not study; let us rather see if the consideration of slow geographical life does not impart new meaning to an old study; let us question if this new meaning is not nearer the truth that we are striving for; then we shall be in a better position to judge if slowness of change is a reason for its neglect. No one makes objection to teaching a young scholar about the growth of an oak tree from an acorn, though it is safe to say that no scholar comes to the belief of the growth of an oak from witnessing it; he is convinced of a change that he cannot wait to see, partly by comparison with trees of a faster growth, and partly by seeing oaks of different sizes, and being led to make reasonable generalizations on his observations. It is the same with our understanding of geographical growth; we cannot see much of it—not even the oldest of us—and yet, after the conception is once gained, it becomes so vivid that one can hardly help expecting to find that a change is perceptible on returning after a time to some familiar locality. One may see a sand bank washed away by a heavy rain, and from this to the washing down of the largest mountain there is only a difference of degree, not of kind. A scholar may easily comprehend the

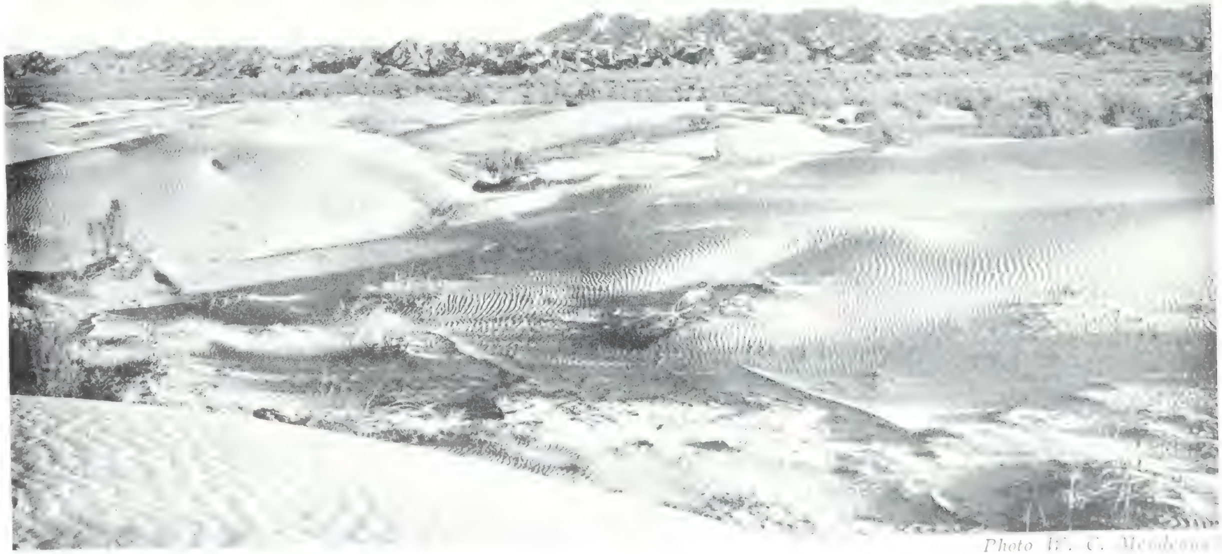


Photo W. C. Mendenhall

DUNES IN THE COLORADO DESERT, CALIFORNIA

The shifting sands! Slowly they move, wave upon wave, drift upon drift; but by day and by night they gather, gather, gather. They overwhelm, they bury, they destroy, and then a spirit of restlessness seizes them and they move off elsewhere, swirl upon swirl, line upon line, in serpentine windings that enfold some new growth or fill in some new valley in the waste. So it happens that the surface of the desert is far from being a permanent affair. There is hardly enough vegetation to hold the sands in place. With little or no restraint upon them they are transported hither and yon at the mercy of the winds. (John C. Van Dyke: *The Desert*, pp. 28-29.)

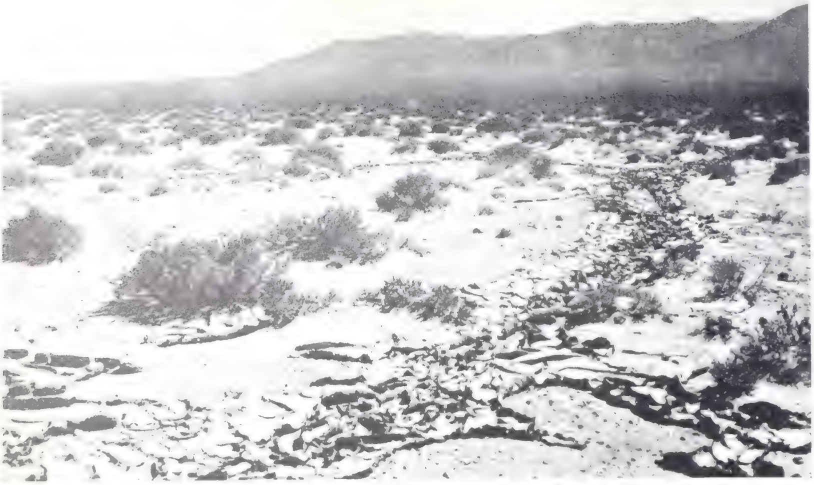
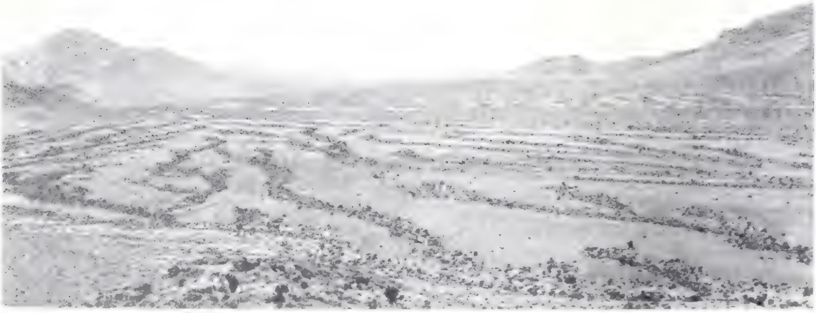


Photo Eliot Blackwelder

A. A MUDFLOW IN THE DESERT

Outer stringer of a narrow thin mudflow about ten days old, on the surface of a great alluvial fan, near Hawthorne, Nevada.



B. A DESERT BASIN IN NEVADA

Lower piedmont slope trenched by brush-filled channels (the black stripes). A great fan enters from the right in the middle distance. Spotted Range, Nevada.

change of form indicated by the differences between the two plains already described, and unless his natural intelligence is obstructed, he can then grasp the idea of geographical growth.

Let us next look at West Virginia; here the interstream hills are so high that they almost merit the name of mountains; the stream branches have become so numerous that no part of the original level upland surface remains; every part has an immediate slope to a stream, and the drainage system is advanced to its highest development. Indeed, we need some aid here from geology to be sure that we are dealing with an individual of the same kind as those already considered, so little likeness is there between this one and the others. But the aid from geology is conclusive; for West Virginia and a large area around it is made up of horizontal layers of bedded rocks that once were at the bottom of the sea, and that still retain the essentially horizontal attitude in which they were laid down; the whole mass of horizontal layers has simply been raised with respect to the surface of its parent ocean. This elevation occurred so long ago that the immaturity such as still characterizes the Red river plains is here long past; the adolescence seen in the Carolina plains is also long ago lived through. In West Virginia we have maturity; there can be no greater variety of form than is here presented. The relief of the surface is at its highest value; for while the interstream hills have not lost much of their original height, the valleys have been sunk about as low as they can be, and hence there is the greatest possible difference of altitude between hill-top and valley-bottom. The streams have become very numerous, and can hardly be more so; every part of the surface is intersected by them. There is no room for more.

From this time on the form of the surface becomes less pronounced. As the destructive changes progress further, the valleys can deepen but little, although the hill-tops must be reduced, and the valley slopes must widen out, and all the topographical expression must weaken as old age is approached. This is the character of central Kentucky. Excepting where the valleys are inclosed in especially hard rocks, they are wide open, and the variable height of the intervening hills makes it clear that they retain no longer all of the height that they once possessed. They are weakening, passing into forms of less and less emphasis, losing variety, becoming old and feeble.

In the next stage we may expect to find valleys so far widened that they should form broad plains, smoothly rolling, essentially a lowland of faint relief, but occasionally diversified with hills of moderate height; and thus the very opposite of the Carolina plains, where the surface is an upland, with occasional valleys. Such an old plain may be seen about the headwaters of the Missouri, in eastern Montana; the general surface is extremely monotonous, gently rolling, and one roll like the next, so that one may easily lose his way in the absence of landmarks. But here and there over the plain mesas of considerable elevation still remain, the reason for their endurance being seen in the layer of hard lava that protects them and retards their destruction, while the rest of the country has wasted away more rapidly. These lava caps are old flows from once active volcanoes; the lava at the time of eruption undoubtedly ran down from its vents to the lowest ground that it could find, and yet it now occupies the highest ground, in virtue of its obstinate refusal to waste away. Every such lava cap is a witness to the greater mass of material over the whole country when the eruption took place, and the destruction of this greater mass must have progressed through the several stages illustrated by the present condition of the Red river plains, the Carolina plains, the mountains of West Virginia, and the hills of central Kentucky, before it could have reached a surface of faint relief. It requires great faith in the evidence here adduced to believe that so stupendous a piece of work has really been accomplished. It is well-nigh incredible, and the observer on the ground is fully justified in doubting it as long as he can, but it cannot be doubted when the evidence is once well seized. It is by no means unparalleled, and much nearer home we may find examples as extraordinary, and as far from easy belief, but as necessary to the convictions of the well-ordered geographer.

Such a plain as that of the upper Missouri may be called a base-level plain, because it has been worn down to the controlling level of drainage, or to what is called the base-level of the region; this being in distinction to an initial or new plain, whose smoothness is due to the short time that its original form has been exposed to developing agencies. A base-level plain represents the ultimate stage in the sequence of a simple cycle of development.

The Appalachian Landscape

The foregoing argument deals only with a "simple cycle"—the erosional sculpturing of a land area that has not been uplifted, warped, or depressed while the sculpturing was in progress. The Appalachian landscape, on the other hand, is the product of several cycles, no one of which was fully completed before an uplift began a new one. The principal features of this type of landscape are well brought out in this account (Willis, 1896, pp. 188-190):

> Let us again look over the Appalachian landscape. It has certainly been sculptured by flowing water, to which the deep channels of the streams are due. Could some Titan fill these channels level with the hilltops of the Greater Valley, he would restore a plain which would extend over the area of soft rocks between the ridges of hard rocks. This is the character of a base-level, and we cannot doubt that such a plain was developed by the streams before they began to cut their present channels. Let us call this plain, which is well preserved in the Shenandoah Valley, the Shenandoah base-level.
>
> Above this base-level the valley ridges rise 200 to 1,800 feet. Neighboring ridges are usually of nearly the same height, and their crests are often level lines, but slightly broken. Such lines are elements of a plain, and, with our eyes opened by suggestion, we may see that they do represent one. But it is only through the extensive landscape studies of Professor

Davis and of Messrs. Hayes and Campbell that we are assured that the ridge tops were once even with the surface of a base-level which was much older than the Shenandoah Plain. Let us call this older plain the Kittatinny base-level, because it is well preserved in the even crest of the long mountain of that name.

To restore the Kittatinny Plain we must fill in with many cubic miles of rock all the Greater Valley between the Blue Ridge and the Alleghany Front, at least level with the ridge crests. This done, however, we should have a broad, dome-shaped elevation 4,000 feet above the sea in southwest Virginia, and sloping gently to the Atlantic and the Mississippi.

Geologists date this Kittatinny Plain as of the so-called Cretaceous period of the earth's history. If we should compare all the ages since the beginning of rocks and oceans on the earth with all the years since human existence began, the Cretaceous period would correspond, perhaps, with the Roman occupation of Britain. Thus vaguely we may indicate that the Cretaceous belongs to the later periods of the earth's development. But the time which has since elapsed has been sufficient for the growth of the Appalachian uplift, and the erosion of its valleys and ranges. From what we have seen in the landscape, we may reconstruct an outline of this growth.

A base-level is the lowest slope to which rivers can reduce a land area.[1] With one margin it touches the sea, from which it rises imperceptibly. Unless it be very old and very completely planed, hills may survive at some distance inland, or over areas of the hardest rocks. Such a surface, which is almost, but not quite, a base-level, is called a *peneplain.* On such a surface the rivers meander in wide oxbows throughout their valleys. There are no marked divides. Under these conditions, the channels of rivers are unstable features, as is that of the Mississippi or the Missouri; and, the fall of a river or system of rivers being very slight, a moderate tilting of the land surface may suffice to change the courses of streams very greatly, or even cause them to flow in a reversed direction. The Kittatinny peneplain was very extensive, and almost completely planed. The only heights in the Appalachian region were hills which are now the mountain summits of western North Carolina, but were then at a lower altitude. The land was flat, featureless, and very slightly elevated above the sea. The courses of the streams had been adjusted during the long period of erosion; and the five rivers flowing eastward had assumed that course in consequence of a tilting of the land toward the Atlantic, which caused them to reverse their courses, which were formerly northwestward. New River did not share in this reversal, and remains to record the original slope from an eastern continent toward an interior sea. From this condition began the growth of the present Appalachian Mountains.

---

[1] This definition of base-level is not generally accepted today.—Ed. Note.

Along a zone corresponding with the present Great Valley the earth's surface rose unequally and very slowly to a maximum height of about 1,400 feet in central Virginia. The elevation grew very gradually, sloping to east and west, and to the Gulf of St. Lawrence on the north, as well as to the Gulf of Mexico on the south. Upon the surface of this broad dome the Susquehanna, Potomac, James, Roanoke, and New rivers meandered in courses closely coincident with those they now possess. They had assumed these courses on the Kittatinny base-level, where the beds of hard and soft rock of the Appalachian ranges were buried beneath the alluvium of their flood plains. As the base-level swelled upward, the rivers descended to the sea with swifter flow. They resumed the work of cutting their channels vertically, as they had done before the Kittatinny Plain was base-leveled, and, removing the mantle of alluvium, they discovered the solid rock ribbed with beds of sandstone and quartzite. Their courses lay across these beds; and, although lines of easier channel cutting lay along the outcrops of soft beds, the great rivers could only persist in their channels, which they corraded as rapidly as the hard beds rose athwart their course. The water gaps by which these rivers pass across the ranges, such as that at Harpers Ferry, and those on the Susquehanna above Harrisburg, and that on the Delaware near Stroudsburg, are the result of the rivers' sawing.

On the Kittatinny Plain many smaller streams flowed across the ranges; and they also, persisting in their courses during the upheaval, cut water gaps in the hard beds. But they could not deepen the gaps as rapidly as did the great rivers, and the work of the smaller streams is now represented by the notches in the ridges high above the Shenandoah Plain. No streams now flow through these little V's: they are *wind gaps* from which a rivulet descends on each side of the ridge.

The First Expedition Down the Colorado

One of the greatest contributors to the modern conception of the cycle of erosion was J. W. Powell. The work on which some of his writings are based is so interesting for its own sake that an account of it is given below.

In 1875 there appeared in Washington the printed report of a remarkable expedition. J. W. Powell, a part of whose work is discussed elsewhere in this volume, had returned from an exploratory trip by boat down the Colorado. His small party had started in May, 1869, from Green River, Wyoming, a station on the newly completed Union Pacific Railroad. At the end of August, after amazing experiences, the battered boats and weary men reached the mouth of Rio Virgen, in southern Nevada, after having floated more than seven hundred miles through canyons, gorges and rapids then unknown. Throughout long stretches the canyon walls were unscalable; if shipwreck had occurred (and no one knew that un-navigable rapids and falls would not bar the way) the party would have been trapped and drowned or starved to death. Even where the cliffs could be climbed, barren, arid country, uninhabited save by Indians, was all that waited above. The chances were greatly against Powell. But he had a keen and eager mind and a thirst for knowledge of new places; the danger apparently never counted with him at all, in spite of the warnings of others. He recounts (Powell, 1875, pp. 6-7):

These cañon gorges, obstructing cliffs and desert wastes, have prevented the traveler from penetrating the country, so that, until the Colorado River Exploring Expedition was organized, it was almost unknown. Yet enough had been seen to foment rumor, and many wonderful stories have been told in the hunter's cabin and prospector's camp. Stories were related of parties entering the gorge in boats, and being carried down with fearful velocity into whirlpools, where all were overwhelmed in the abyss of waters; others, of underground passages for the great river, into which boats had passed never to be seen again. It was currently believed that the river was lost under the rocks for several hundred miles. There were other accounts of great falls, whose roaring music could be heard on the distant mountain-summits. There were many stories current of parties wandering on the brink of the cañon, vainly endeavoring to reach the waters below, and perishing with thirst at last in sight of the river which was roaring its mockery into dying ears.

The Indians, too, have woven the mysteries of the cañons into the myths of their religion. Long ago, there was a great and wise chief, who mourned the death of his wife, and would not be comforted until Ta-vwoats, one of the Indian gods, came to him, and told him she was in a happier land, and offered to take him there, that he might see for himself. if, upon his return, he would cease to mourn. The great chief promised. Then Ta-vwoats made a trail through the mountains that intervene between that beautiful land, the balmy region in the great west, and this, the desert home of the poor Nu′ma.

This trail was the cañon gorge of the Colorado. Through it he led him; and, when they had returned, the deity exacted from the chief a promise that he would tell no one of the joys of that land, lest, through discontent with the circumstances of this world, they should desire to go to heaven. Then he rolled a river into the gorge, a mad, raging stream, that should engulf any that might attempt to enter thereby.

> More than once have I been warned by the Indians not to enter this cañon. They considered it disobedience to the gods and contempt for their authority, and believed that it would surely bring upon me their wrath.

On his decision to make the trip, Powell (1875, p. 7) is reticent and modest:

> For two years previous to the exploration, I had been making some geological studies among the heads of the cañons leading to the Colorado, and a desire to explore the Grand Cañon itself grew upon me. Early in the spring of 1869, a small party was organized for this purpose. Boats were built in Chicago, and transported by rail to the point where the Union Pacific Railroad crosses the Green River. With these we were to descend the Green into the Colorado, and the Colorado down to the foot of the Grand Cañon.

The account of the voyage is given in the form of a diary. It begins thus (pp. 8-9):

> *May* 24, 1869.—The good people of Green River City turn out to see us start. We raise our little flag, push the boats from shore, and the swift current carries us down.
>
> Our boats are four in number. Three are built of oak; stanch and firm; doubled-ribbed, with double stem and stern posts, and further strengthened by bulkheads, dividing each into three compartments.
>
> Two of these, the fore and aft, are decked, forming water-tight cabins. It is expected these will buoy the boats should the waves roll over them in rough water. The little vessels are twenty-one feet long, and, taking out the cargoes, can be carried by four men.
>
> The fourth boat is made of pine, very light, but sixteen feet in length, with a sharp cut-water, and every way built for fast rowing, and divided into compartments as the others.
>
> We take with us rations deemed sufficient to last ten months;

> for we expect, when winter comes on and the river is filled with ice, to lie over at some point until spring arrives; so we take with us abundant supplies of clothing. We have also a large quantity of ammunition and two or three dozen traps. For the purpose of building cabins, repairing boats, and meeting other exigencies, we are supplied with axes, hammers, saws, augers, and other tools, and a quantity of nails and screws. For scientific work, we have two sextants, four chronometers, a number of barometers, thermometers, compasses, and other instruments.
>
> The flour is divided into three equal parts; the meat and all other articles of our rations in the same way. Each of the larger boats has an ax, hammer, saw, auger, and other tools, so that all are loaded alike. We distribute the cargoes in this way, that we may not be entirely destitute of some important article should any one of the boats be lost. In the small boat, we pack a part of the scientific instruments, three guns, and three small bundles of clothing only. In this, I proceed in advance, to explore the channel.
>
> J. C. Sumner and William H. Dunn are my boatmen in the "Emma Dean"; then follows "Kitty Clyde's Sister," manned by W. H. Powell and G. Y. Bradley; next, the "No Name," with O. G. Howland, Seneca Howland, and Frank Goodman; and last comes the "Maid of the Cañon," with W. R. Hawkins and Andrew Hall.
>
> Our boats are heavily loaded, and only with the utmost care is it possible to float in the rough river without shipping water.

Very soon the party encountered the first of the scores of rapids that lay between them and the mouth of the Grand Canyon. They ran the rapids in this way (Powell, p. 14):

> Entering Flaming Gorge, we quickly run through it on a swift current, and emerge into a little park. Half a mile below, the river wheels sharply to the left, and we turned into another cañon cut into the mountain. We enter the narrow passage.

> On either side, the walls rapidly increase in altitude. On the left are overhanging ledges and cliffs five hundred—a thousand—fifteen hundred feet high.
>
> On the right, the rocks are broken and ragged, and the water fills the channel from cliff to cliff. Now the river turns abruptly around a point to the right, and the waters plunge swiftly down among great rocks; and here we have our first experience with cañon rapids. I stand up on the deck of my boat to seek a way among the wave beaten rocks. All untried as we are with such waters, the moments are filled with intense anxiety. Soon our boats reach the swift current; a stroke or two, now on this side, now on that, and we thread the narrow passage with exhilarating velocity, mounting the high waves, whose foaming crests dash over us, and plunging into the troughs, until we reach the quiet water below; and then comes a feeling of great relief. Our first rapid is run. Another mile, and we come into the valley again.

On June 9 one of the boats, the *No Name,* was smashed to pieces in trying to shoot the rapids of Lodore, and a part of the provisions was lost. In various other rapids the boats lost oars, but Powell resourcefully sawed new ones out of drift logs.

Almost every day, some member of the party climbed as far as he could go up the canyon walls in order to secure as much information as possible about the surrounding country. Here is a typical account (Powell, pp. 78-79) of one of Powell's climbs:

> *August 12.*—The rocks above camp are rust-colored sandstones and conglomerates. Some are very hard; others quite soft. These all lie nearly horizontal, and the beds of softer material have been washed out, and left the harder, thus forming a series of shelves. Long lines of these are seen, of varying thickness, from one or two to twenty or thirty feet, and the spaces between have the same variability. This morning, I spend two or three hours in climbing among these shelves, and then I pass above them, and go up a long slope, to the foot of the cliff, and try to discover some way by which I can

reach the top of the wall; but I find my progress cut off by an amphitheater. Then, I wander away around to the left, up a little gulch, and along benches, and climb, from time to time, until I reach an altitude of nearly two thousand feet, and can get no higher. From this point, I can look off to the west, up side cañons of the Colorado, and see the edge of a great plateau, from which streams run down into the Colorado, and deep gulches, in the escarpment which faces us, continued by cañons, ragged and flaring, and set with cliffs and towering crags, down to the river. I can see far up Marble Cañon, to long lines of chocolate-colored cliffs, and above these, the Vermilion Cliffs. I can see, also, up the Colorado Chiquito, through a very ragged and broken cañon, with sharp salients set out from the walls on either side, their points overlapping, so that a huge tooth of marble, on one side, seems to be set between two teeth on the opposite; and I can also get glimpses of walls, standing away back from the river, while over my head are mural escarpments, not possible to be scaled.

At the entrance to the Grand Canyon, he states (Powell, p. 80):

August 13.—We are now ready to start on our way down the Great Unknown. Our boats, tied to a common stake, are chafing each other, as they are tossed by the fretful river. They ride high and buoyant, for their loads are lighter than we could desire. We have but a month's rations remaining. The flour has been resifted through the mosquito net sieve; the spoiled bacon has been dried, and the worst of it boiled; the few pounds of dried apples have been spread in the sun, and reshrunken to their normal bulk; the sugar has all melted, and gone on its way down the river; but we have a large sack of coffee. The lighting of the boats has this advantage: they will ride the waves better, and we shall have but little to carry when we make a portage.

We are three-quarters of a mile in the depths of the earth, and the river shrinks into insignificance, as it dashes its angry waves against the walls and cliffs, that rise to the world above;

they are but puny ripples, and we but pigmies, running up and down the sands, or lost among the boulders.

We have an unknown distance yet to run; an unknown river yet to explore. What falls there are, we know not; what rocks beset the channel, we know not; what walls rise over the river, we know not. Ah, well! we may conjecture many things. The men talk as cheerfully as ever; jests are bandied about freely this morning; but to me the cheer is somber and the jests are ghastly.

And part way through the canyon (Powell, pp. 88-89):

August 17.—Our rations are still spoiling; the bacon is so badly injured that we are compelled to throw it away. By an accident, this morning, the saleratus is lost overboard. We have now only musty flour sufficient for ten days, a few dried apples, but plenty of coffee. We must make all haste possible. If we meet with difficulties, as we have done in the cañon above, we may be compelled to give up the expedition, and try to reach the Mormon settlements to the north. Our hopes are that the worst places are passed, but our barometers are all so much injured as to be useless, so we have lost our reckoning in altitude, and know not how much descent the river has yet to make.

The stream is still wild and rapid, and rolls through a narrow channel. We make but slow progress, often landing against a wall, and climbing around some point, where we can see the river below. Although very anxious to advance, we are determined to run with great caution, lest, by another accident, we lose all our supplies. How precious that little flour has become! We divide it among the boats, and carefully store it away, so that it can be lost only by the loss of the boat itself.

We make ten miles and a half, and camp among the rocks, on the right. We have had rain, from time to time, all day, and have been thoroughly drenched and chilled; but between

> showers the sun shines with great power, and the mercury in our thermometers stands at 115°, so that we have rapid changes from great extremes, which are very disagreeable. It is especially cold in the rain to-night. The little canvas we have is rotten and useless; the rubber ponchos, with which we started from Green River City, have all been lost; more than half the party is without hats, and not one of us has an entire suit of clothes, and we have not a blanket apiece. So we gather drift wood, and build a fire; but after supper the rain, coming down in torrents, extinguishes it, and we sit up all night, on the rocks, shivering, and are more exhausted by the night's discomfort than by the day's toil.

Near the lower end of the Grand Canyon, three of the men decided to quit the party, thinking the risks of an overland trip to the nearest Mormon settlements to be less than the danger of the boats. But only a week later the boats reached the Rio Virgen, with houses and friends. Powell's relief was great the night after their arrival. He writes (Powell, p. 103):

> Ever before us has been an unknown danger, heavier than immediate peril. Every waking hour passed in the Grand Cañon has been one of toil. We have watched with deep solicitude the steady disappearance of our scant supply of rations, and from time to time have seen the river snatch a portion of the little left, while we were ahungered. And danger and toil were endured in those gloomy depths, where oft-times the clouds hid the sky by day, and but a narrow zone of stars could be seen at night. Only during the few hours of deep sleep, consequent on hard labor, has the roar of the waters been hushed. Now the danger is over; now the toil has ceased; now the gloom has disappeared; now the firmament is bounded only by the horizon; and what a vast expanse of constellations can be seen!
>
> The river rolls by us in silent majesty; the quiet of the camp is sweet; our joy is almost ecstasy.

It was later learned that the three men who had deserted the expedition on the eve of its success, had been attacked and killed by Indians while on their overland journey.

The Classification of Valleys

His narrative concluded, Powell turned to a systematic description of what he had seen. For lucidity, and for accuracy of reasoning, his account has seldom been equaled. Consider his explanation (Powell, pp. 152-153) of the course of Green River that cuts directly through the great anticline of the Uinta Mountains:

> To a person studying the physical geography of this country, without a knowledge of its geology, it would seem very strange that the river should cut through the mountains, when, apparently, it might have passed around them to the east, through valleys, for there are such along the north side of the Uintas, extending to the east, where the mountains are degraded to hills, and, passing around these, there are other valleys, extending to the Green, on the south side of the range. Then, why did the river run through the mountains?
>
> The first explanation suggested is that it followed a previously formed fissure through the range; but very little examination will show that this explanation is unsatisfactory. The proof is abundant that the river cut its own channel; that the cañons are gorges of corrasion. Again, the question returns to us, why did not the stream turn around this great obstruction, rather than pass through it? The answer is that the river had the right of way; in other words, it was running ere the mountains were formed; not before the rocks of which the mountains are composed, were deposited, but before the formations were folded, so as to make a mountain range.
>
> The contracting or shriveling of the earth causes the rocks near the surface to wrinkle or fold, and such a fold was started athwart the course of the river. Had it been suddenly formed, it would have been an obstruction sufficient to turn the water in a new course to the east, beyond the extension of the wrin-

kle; but the emergence of the fold above the general surface of the country was little or no faster than the progress of the corrasion of the channel. We may say, then, that the river did not cut its way *down* through the mountains, from a height of many thousand feet above its present site, but, having an elevation differing but little, perhaps, from what it now has, as the fold was lifted, it cleared away the obstruction by cutting a cañon, and the walls were thus elevated on either side. The river preserved its level, but mountains were lifted up; as the saw revolves on a fixed pivot, while the log through which it cuts is moved along. The river was the saw which cut the mountains in two.

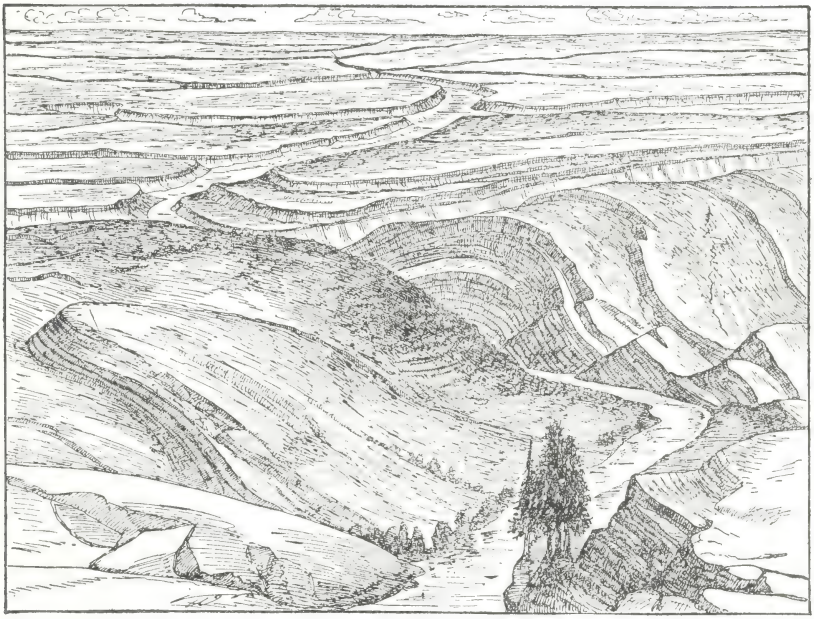


FIG. 11.—THE FIRST ILLUSTRATION OF AN ANTECEDENT VALLEY. FROM AN ORIGINAL ENGRAVING IN POWELL'S REPORT.

He reaches the conclusion (Powell, p. 163)

that the drainage was established antecedent to the corrugation or displacement of the beds by faulting and folding. I

> propose to call such valleys, including the orders and varieties before mentioned, *antecedent valleys* [Fig. 11].[1]

Further on he notes that the drainage of the Plateaus is in the main independent of the structure of the rocks, and concludes (Powell, pp. 165-166):

> There can be no doubt that the present courses of the streams were determined by conditions not found in the rocks through which the channels are now carved, but that the beds in which the streams had their origin when the district last appeared above the level of the sea, have been swept away. I propose to call such *superimposed valleys.* Thus the valleys under consideration, if classified on the basis of their relation to the rocks in which they originated, would be called *consequent valleys,* but if classified on the basis of their relation to the rocks in which they are now found, would be called *superimposed valleys.*

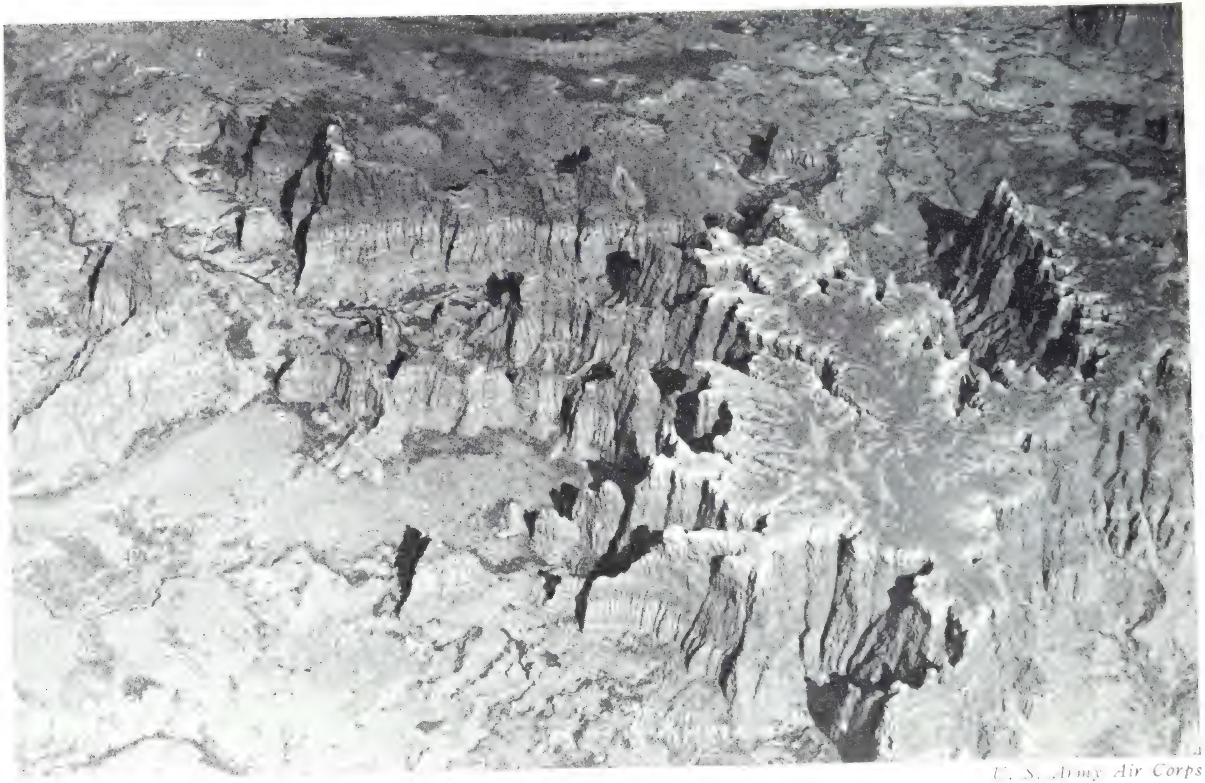
Another illustration of Powell's ability to visualize the whole of a process, only a small part of which he could actually see, lies in this passage (Powell, pp. 171-172):

> When a great fold emerges from the sea, or rises above its base level of erosion, the axis appears above the water (or base level) first, and is immediately attacked by the rains, and its sands are borne off to form new deposits. It has before been explained that the emergence of the fold is but little faster than the degradation of its surface, but, as it comes up, the wearing away is extended still farther out on the flanks, and the same beds are attacked in the new land which have already been carried away nearer the center of the fold. In this way the action of erosion is continued on the same bed from the up-turned axis toward the down-turned axis, and it may and does often happen that any particular bed may be entirely

---

[1] Although this principle advanced by Powell has been found to apply to many valleys in various parts of the world, the Uinta gorges have recently been proved to be the result of superimposition of the streams that cut them.—Ed. Note.

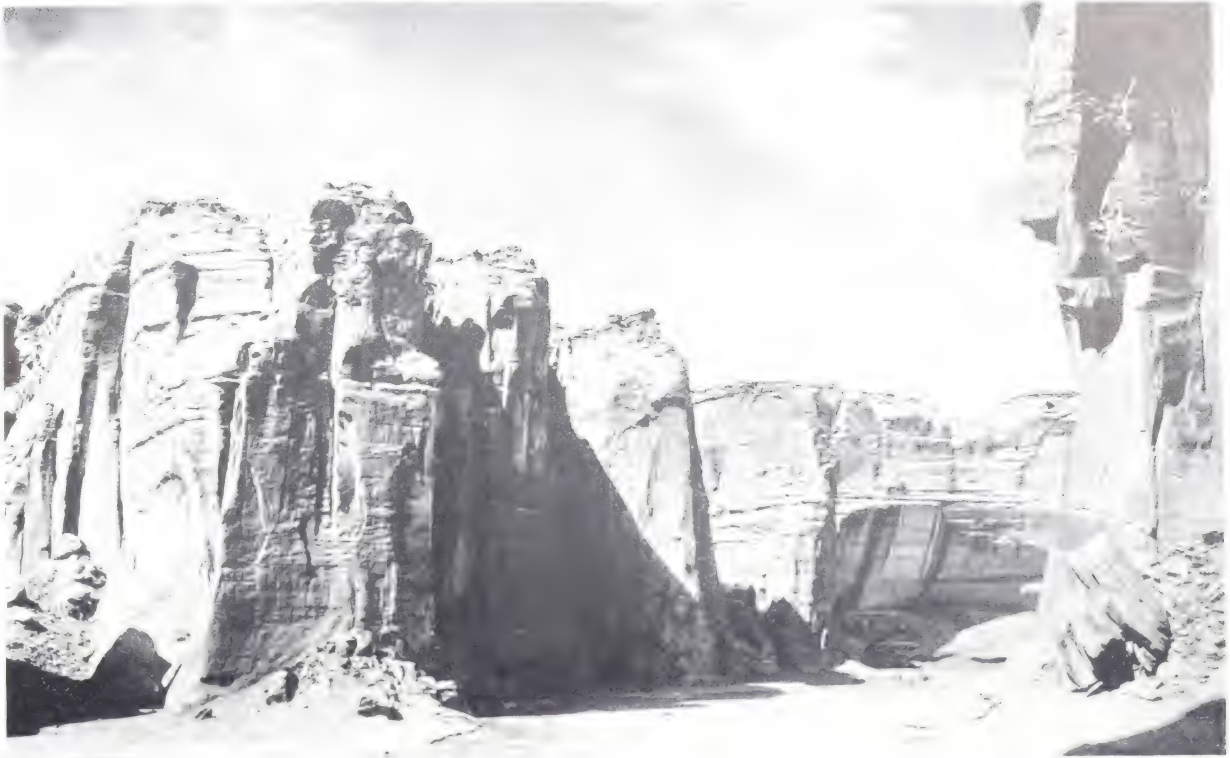
PLATE XL



U. S. Army Air Corps

BUTTES SEEN FROM THE AIR

Remnants of a dissected plateau, Navajo Indian Reservation, Arizona.



U. S. Geological Survey

CANYON DE CHELLY, ARIZONA

Cut vertically into massive sandstone. The tiny horse and wagon beside the stream show the canyon's great size.

carried away, with many underlying rocks, near the former line, before it is attacked near the latter. Now, as the beds are of heterogeneous structures, some hard and others soft, the harder beds withstand the action of the storms, while the softer beds are rapidly carried away.

The manner in which these beds are degraded is very different. The softer are washed from the top, but the harder are little affected by the direct action of the waters—they are torn down by another process. As the softer beds disappear, the harder are undermined, and are constantly breaking down; are crushed, more or less, by the fall, and scattered over, and mingled with the softer beds, and are carried away with them. But the progress of this undermining and digging down of the cliff is parallel with the upturned axis of the fold, so that the cliffs face such an axis.

The Record of the Strata Exposed in the Grand Canyon

In the Grand Canyon, this section is exposed: at the bottom of the gorge are schists intruded by bands of granite, with basic dikes cutting the whole mass, which is beveled to a plane surface. Above this are slightly metamorphosed sandstones and shales, tilted and beveled. Resting unconformably above these are horizontal sedimentary rocks. Powell (pp. 213-214) interprets the section:

> Three times has this great region been left high and dry by the ever shifting sea; three times have the rocks been fractured and faulted; three times have floods of lava been poured up through the crevices, and three times have the clouds gathered over the rocks, and carved out valleys with their storms. The first time was after the deposition of the schists; the second was after the deposition of the red sandstones; the third time is the present time. The plateaus and mountains of the first and second periods have been destroyed or buried; their eventful history is lost; the rivers that ran into the sea are dead, and their waters are now rolling as tides, or coursing in other channels. Were there cañons then? I think not.

The conditions necessary to the formation of cañons are exceptional in the world's history.

We have looked back unnumbered centuries into the past, and seen the time when the schists in the depths of the Grand Cañon were first formed as sedimentary beds beneath the sea; we have seen this long period followed by another of dry land—so long that even hundreds, or perhaps thousands, of feet of beds were washed away by the rains; and, in turn, followed by another period of ocean triumph, so long, that at least ten thousand feet of sandstones were accumulated as sediments, when the sea yielded dominion to the powers of the air, and the region was again dry land. But aerial forces carried away the ten thousand feet of rocks, by a process slow yet unrelenting, until the sea again rolled over the land, and more than ten thousand feet of rocky beds were built over the bottom of the sea; and then again the restless sea retired, and the golden, purple, and black hosts of heaven made missiles of their own misty bodies—balls of hail, flakes of snow, and drops of rain—and when the storm of war came, the new rocks fled to the sea. Now we have cañon gorges and deeply eroded valleys, and still the hills are disappearing, the mountains themselves are wasting away, the plateaus are dissolving, and the geologist, in the light of the past history of the earth, makes prophecy of a time when this desolate land of Titanic rocks shall become a valley of many valleys, and yet again the sea will invade the land, and the coral animals build their reefs in the infinitesimal laboratories of life, and lowly beings shall weave nacre-lined shrouds for themselves, and the shrouds shall remain entombed in the bottom of the sea, when the people shall be changed, by the chemistry of life, into new forms; monsters of the deep shall live and die, and their bones be buried in the coral sands. Then other mountains and other hills shall be washed into the Colorado Sea, and coral reefs, and shales, and bones, and disintegrated mountains, shall be made into beds of rock, for a new land, where new rivers shall flow.

Thus ever the land and sea are changing; old lands are buried, and new lands are born, and with advancing periods new complexities of rock are found; new complexities of life evolved.

The Desert

The systematic discussion of a landscape, although absolutely essential to a complete understanding of the various parts of the Earth's surface, has symmetry of form perhaps but not beauty of style. Good textbooks explain the cycle of erosion in arid regions; below are given passages (Lord, 1883, pp. 4-5) which are intended primarily to add atmosphere and flavor to such expositions.

Descend into the midst of the desert and look closely around. The soft brown slopes are changed to scarred and crumbling heaps of rocks, the shining lakes to beds of alkaline earth seamed with innumerable cracks, and the grey plains to wastes of sand dotted thickly with clumps of sage brush. Here and there at long intervals stalks of bunch-grass thrust their stiff blades out of the arid soil, covered often with clinging crystals of salt which sparkle like frost in the sunlight. Dusky lizards dart about among the blackened rocks of the isolated ridges, and lizards with yellow backs sprawl on the hot sand. A little flock of sparrows may hover about some mountain spring, a coyote sometimes ambles over the hills, and jack-rabbits scurry through the sage brush in ridiculous alarm, but the oppressive stillness is rarely broken by the movement of anything with life. Nature seems to sleep, except when the brooding air is stirred by the passage of clouds and columns of feathery dust borne by eddying whirlwinds over the desert. The sight recalls the words of Marco Polo, describing the deserts about Khubees, "where there is neither fruit nor trees, and the water is bitter and bad, so that a traveler must carry it and food for himself, but the beasts drink that on the road, though very unwillingly." It was over this dreary land that the Mexican guide of Fremont pointed, from the mountain pass at the head of the river San Joaquin. "There," said he, "there are the great llanos. There is neither water nor grass—every animal which goes out upon them dies."

John C. Van Dyke has written many interesting things concerning the deserts of the southern Great Basin. Certain extracts from his book *The Desert* (Van Dyke, 1901, pp. 23-26, 32-34) are quoted here:

> The first going-down into the desert is always something of a surprise. The fancy has pictured one thing; the reality shows quite another thing. Where and how did we gain the idea that the desert was merely a sea of sand? Did it come from that geography of our youth with the illustration of the sand-storm, the flying camel, and the over-excited Bedouin? Or have we been reading strange tales told by travellers of perfervid imagination—the Marco Polos of to-day? There is, to be sure, some modicum of truth even in the statement that misleads. There are "seas" or lakes or ponds of sand on every desert; but they are not so vast, not so oceanic, that you ever lose sight of the land.
>
> What land? Why, the mountains. The desert is traversed by many mountain ranges, some of them long, some short, some low, and some rising upward ten thousand feet. They are always circling you with a ragged horizon, dark-hued, bare-faced, barren—just as truly desert as the sands which were washed down from them. Between the ranges there are wide-expanding plains or valleys. The most arid portions of the desert lie in the basins of these great valleys—flat spaces that were once the beds of lakes, but are now dried out and left perhaps with an alkaline deposit that prevents vegetation. Through these valleys run arroyos or dry stream-beds—shallow channels where gravel and rocks are rolled during cloudbursts and where sands drift with every wind. At times the valleys are more diversified, that is, broken by benches of land called mesas, dotted with small groups of hills called lomas, crossed by long stratified faces of rock called escarpments.
>
> With these large features of landscape common to all coun-

tries, how does the desert differ from any other land? Only in the matter of water—the lack of it. If Southern France should receive no more than two inches of rain a year for twenty years it would, at the end of that time, look very like the Sahara, and the flashing Rhone would resemble the sluggish yellow Nile. If the Adirondack region in New York were comparatively rainless for the same length of time we should have something like the Mojave Desert, with the Hudson changed into the red Colorado. The conformations of the lands are not widely different, but their surface appearances are as unlike as it is possible to imagine.

For the whole face of a land is changed by the rains. With them come meadow-grasses and flowers, hillside vines and bushes, fields of yellow grain, orchards of pink-white blossoms. Along the mountain sides they grow the forests of blue-green pine, on the peaks they put white caps of snow; and in the valleys they gather their waste waters into shining rivers and flashing lakes. This is the very sheen and sparkle—the witchery—of landscapes which lend allurement to such countries as New England, France, or Austria, and make them livable and lovable lands.

But the desert has none of these charms. Nor is it a livable place. There is not a thing about it that is "pretty," and not a spot upon it that is "picturesque" in any Berkshire-Valley sense. The shadows of foliage, the drift of clouds, the fall of rain upon leaves, the sound of running waters—all the gentler qualities of nature that minor poets love to juggle with—are missing on the desert. It is stern, harsh, and at first repellent. But what tongue shall tell the majesty of it, the eternal strength of it, the poetry of its wide-spread chaos, the sublimity of its lonely desolation! And who shall paint the splendor of its light; and from the rising up of the sun to the going down of the moon over the iron mountains, the glory of its wondrous coloring! It is a gaunt land of splintered peaks, torn valleys, and hot skies. And at every step there is the suggestion of the fierce, the defiant, the defensive. Everything within its borders seems fighting to maintain itself against destroying forces. There is a war of elements and a struggle for existence going on here that for ferocity is unparalleled elsewhere in nature.

Yes; there is some water on the deserts, some rainfall each year. Even Sahara gets its occasional showers, and the Colorado and the Mojave show many traces of the cloud-burst. The dark thunder clouds that occasionally gather over the desert seem at times to reserve all their stores of rain for one place. The fall is usually short-lived but violent; and its greatest force is always on the mountains. There is no sod, no moss, to check or retard the flood; and the result is a great rush of water to the low places. In the canyons the swollen streams roll down bowlders that weigh tons, and in the ravines many a huge barranca is formed in a single hour by these rushing waters. On the lomas and sloping valleys they are not less destructive, running in swift streams down the hollows, and whirling stones, sand, and torn bushes into the old river-beds.

In a very short time there is a great torrent pouring down the valley—a torrent composed of water, sand, and gravel in about equal parts. It is a yellow, thick stream that has nothing but disaster for the man or beast that seeks to swim it. Many a life has been lost there. The great onset of the water destroys anything like buoyancy, and the tendency is to drag down and roll the swimmer like a bowlder. Even the enormous strength of the grizzly bear has been known to fail him in these desert rivers. They boil and seethe as though they were hot; and they rush on against banks, ripping out the long roots of mesquite, and swirling away tons of undermined gravel as though it were only so much snow. At last after miles of this millracing the force begins to diminish, the streams reach the flat lake-beds and spread into broad, thin sheets; and soon they have totally vanished, leaving scarcely a rock behind.

In connection with the account of a "sheetflood" just quoted, there appears another eye-witness story of a mudflow (Douglas, 1928, p. 470) that occurred in 1905 at the southern end of the San Joaquin Valley, in California, a semiarid region:

> Some time before it [the mudflow] made its appearance, its dull and heavy roar could be heard from up the canyon, quite distinct from and rising above all of the other noises of the storm, and reminding one of the breakers against a rocky shore. As it issued from the narrow mouth of the side canyon it was accompanied by a cloud of dust occasioned by the breaking up of huge masses of dry soil from projecting points in its rush down the canyon. Through the dust glimpses could be had of great piles of drift with an occasional tree turning end over end. After descending about one-half mile from the mouth of the smaller canyon it came to a full stop, only to be succeeded in a few minutes by another wave, larger and swifter than the first. There was no dust with this or any of the succeeding waves; but immense masses of rock, many of which must have weighed several tons, were apparently dancing along, light as corks, on the surface, being supported by the earthy mass beneath. This wave extended about a half-mile further down the canyon than the first, when it also came to a stop, having spread to the full width of the main canyon (here about one-quarter mile). In a few minutes another wave of mud swept by, followed by others at intervals of a few minutes, each succeeding wave getting thinner and traveling with greater velocity than the preceding one, until finally in about one-half hour it was mud no longer but a steady rush of yellow foaming water, at first probably one hundred yards wide in the main canyon, gradually reducing its width and increasing its depth and swiftness as it washed out a channel in the soft mud. As to the distance and size of rocks moved by this "cloudburst,"—there is a sandstone boulder which has come from seven miles up the canyon and has approximately the following dimensions: height 8 feet, length 16 feet, width 12 feet. On the plains about five miles east of the canyon

mouth, several masses much larger than this one can be seen. These were also brought down a canyon by "cloudbursts."

During the long intervals between cloudbursts in dry regions, the wind is busy sweeping up sand and dust, whirling it forward, heaping it into dunes and exporting it into other regions. Consider this vivid description (Van Dyke, 1901, pp. 16-17, 30-32) of the work of desert winds:

> Fifty miles away one could see the desert sand-whirls moving slowly over the beds in tall columns two thousand feet high and shining like shafts of marble in the sunlight. How majestically they moved, their feet upon earth, their heads towering into the sky!
>
> And then the desert winds that raised at times such furious clouds of sand! All the air shone like gold dust and the sun turned red as blood. Ah! what a stifling sulphureous air! Even on the mountain tops that heavy air could be felt, and down in the desert itself the driving particles of sand cut the face and hands like blizzard-snow. The ponies could not be made to face it. They turned their backs to the wind and hung their heads between their fore feet. And how that wind roared and whistled through the thin grease wood! The scrubby growths leaned and bent in the blast, the sand piled high on the trunks; and nothing but the enormous tap-roots kept them from being wrenched from the earth.
>
> And danger always followed the high winds. They blew the sands in clouds that drifted full and destroyed the trails. In a single night they would cover up a water hole, and in a few days fill in an arroyo where water could be got by digging. The sands drove like breakers on a beach, washing and wearing everything up to the bases of the mountains. And the fine sand reached still higher. It whirled up the canyons and across the saddles, it eddied around the enormous taluses, it even flung itself upon the face walls of the mountain and left the smoothing marks of its fingers upon the sharp pinnacles of the peak.

In open places these desert winds are sometimes terrific in force though usually they are moderate and blow with steadiness from certain directions. As you feel them softly blowing against your cheek it is hard to imagine that they have any sharp edge to them. Yet about you on every side is abundant evidence of their works. The sculptor's sand-blast works swifter but not surer. Granite and porphyry cannot withstand them, and in time they even cut through the glassy surface of lava. Their wear is not here or there, but all over, everywhere. The edge of the wind is always against the stone. Continually there is the slow erosion of canyon, crag, and peak; forever there is a gnawing at the bases and along the face-walls of the great sierras. Grain by grain, the vast foundations, the beetling escarpments, the high domes in air are crumbled away and drifted into the valleys. Nature heaved up these mountains at one time to fulfil a purpose: she is now taking them down to fulfil another purpose. If she has not water to work with here as elsewhere she is not baffled of her purpose. Wind and sand answer quite as well.

But the cutting of the wind is not always even or uniform, owing to the inequalities in the fibre of rock; and often odd effects are produced by the softer pieces of rock wearing away first and leaving the harder section exposed to view. Frequently these remainders take on fantastic shapes and are likened to things human, such as faces, heads, and hands. In the San Gorgonio Pass the rock-cuttings are in parallel lines, and occasionally a row of garnets in the rock will make the jewel-pointed fingers of a hand protruding from the parent body. Again shafts of hard granite may make tall spires and turrets upon a mountain peak, a vein of quartz may bulge out in a white or yellow or rose-colored band; and a ridge of black lava, reaching down the side of a foothill, may creep and heave like the backbone of an enormous dragon.

The following is taken from the narrative of William L. Manly (1927, pp. 138 ff.) who made his way from Michigan to California during the gold rush of 1849-50. After many hardships he joined a wagon-train bound southwest from Salt Lake City to Los Angeles over a new route:

The party kept rolling along as fast as possible, but the mountains and valleys grew more barren and water more scarce all the time. When found, the water would be in holes at the outlet of some cañon, or in little pools which had filled up with rain that had fallen on the higher ground. Not a drop of rain had fallen on us since we started on this cut-off, and every night was clear and warm. The elevated parts of the country seemed to be isolated buttes, with no running streams between them but, instead, dry lakes with a smooth clay bed, very light in color and so hard that the track of an ox could not be seen on its glittering surface. At a distance these clay beds looked like water shining in the sun and they were generally about three times as far off as any one would judge, the air was so clear. This mirage, or resemblance to water, was so perfect as often to deceive us, and almost to cause our ruin on one or two occasions. . . .

I was glad enough to see the day break over the eastern mountains, and light up the vast, barren country I could see on every hand around me. When the sun was fairly up I took a good survey of the situation and it seemed as if pretty near all creation was in sight. North and west was a level plain, fully one hundred miles wide it seemed, and from anything I could see it would not afford a traveler a single drink in the whole distance or give a poor ox many mouthfuls of grass. On the western edge it was bounded by a low, black, and rocky range extending nearly north and south for a long distance and no pass through it which I could see, and beyond this range was still another one, apparently parallel to it. . . .

I had learned by experience that objects a day's walk distant seemed close by in such a light, and that when clear lakes appeared only a little distance in our front, we might search and search and never find them. We had to learn how to look for water in this peculiar way. In my Wisconsin travel I had learned that when I struck a ravine I must go down to look for living water, but here we must invariably travel upward, for the water was only found in the high mountains.

I could see in my glass the train of wagons moving slowly over the plain toward what looked to me like a large lake. I estimated the point they would reach by night, and then took a straight course for it all day long in steady travel. It was some time after dark, and I was still a quarter of a mile from the camp-fires, when in the bed of a cañon I stepped into some mud, which was a sign of water. I poked around in the dark for awhile and soon found a little pool of it, and having been without a drop of it for two days I lay down and took a hasty drink. It did not seem to be very clear or clean, but it was certainly wet, which was the main thing just then. The next morning I went to the pond of water, and found the oxen had been watered there. They stirred up the mud a good deal and had drunk off about all the clear part, which seemed to refresh them very much. I found the people in the camp on the edge of the lake I had seen from the mountain, and fortunately it contained about a quarter of an inch of water. They had dug some holes here, which filled up, and they were using this water in the camp. . . .

We had not gone long on this course before we saw that we must cross the valley and get over to the west side. To do this we must cross through some water, and for fear the ground might be miry, I went to a sand hill near by and got a mesquite stick about three feet long with which to sound out our way. I rolled up my pants, pulled off my moccasins, and waded in, having the teams stand still till I could find out whether it was safe for them to follow or not by ascertaining the depth of the water and the character of the bottom.

The water was very clear and the bottom seemed uneven, there being some deep holes. Striking my stick on the bottom, it seemed solid as a rock, and breaking off a small projecting point, I found it to be solid rock salt. As the teams rolled along they scarcely roiled the water. It looked to me as if the whole valley, which might be a hundred miles long, might have been a solid bed of rock salt. Before we reached this water there were many solid blocks of salt lying around, covered with a little dirt on the top.

The second night we found a good spring of fresh water coming out from the bottom of the snow peak almost over our heads. The small flow from it spread out over the sand and sank in a very short distance and there was some quite good grass growing around. This was a temporary relief, but it brought us face to face with stranger difficulties and a more hopeless outlook.

We had been in the region long enough to know that the higher mountains contained the most water, and that the valleys had bad water or none at all, so that while the lower altitude to the south gave some promise of easier crossing it gave us no promise of water or grass, without which we must certainly perish. In a certain sense we were lost. The clear nights and days furnished us with the means of telling the points of the compass as the sun rose and set, but not a sign of life in nature's wide domain had been seen for a month or more. A vest pocketful of powder and shot would last a good hunter till he starved to death, for there was not a living thing to shoot, great or small.

. . . In the morning we filled our canteens, which we had made by binding two powder cans together with strips of cloth, and started for the summit near by. From this was the grandest sight we had ever beheld. Looking east, we could see the country we had been crawling over since November 4. "Just look at the cursed country we have come over!" said Rogers as he pointed toward it. To the north was the biggest mountain we had ever seen, peaks on peaks, towering far above our heads, and covered with snow which was apparently everlasting.

The mountain seemed to have very few trees on it, and in extent, as it reached away to the north, seemed interminable. To the south was a nearly level plain, and to the west I thought

I could dimly see a range of mountains that held a little snow on their summits, but on the main range to the south there was none. It seemed to me the dim snowy mountains must be as far as 200 miles away, but of course I could not judge accurately. After looking at this grand but worthless landscape long enough to take in its principal features, we asked each other what we supposed the people we had left behind would think to see mountains so far ahead. We knew that they had an idea that the coast range was not very far ahead, but we saw at once that to go over all these mountains and return within the limit of fifteen days, which had been agreed upon between us, would probably be impossible, but we must try as best we could, so down the rocky steep we clambered and hurried on our way. In places the way was so steep that we had to help each other down, and the hard work made us perspire freely so that water was a prime necessity. In one place near here we found a little water and filled our canteens, besides drinking a good present supply. There were two low, black rocky ranges directly ahead of us which we must cross.

When part way down the mountain a valley or depression opened up in that direction, up which it seemed as if we could look a hundred miles. Near by and a short distance north was a lake of water, and when we reached the valley we crossed a clear stream of water flowing slowly toward the lake.

Being in need of water, we rushed eagerly to it and prepared to take a big drink, but the tempting fluid was as salt as brine and made our thirst all the more intolerable. Nothing grew on the bank of this stream and the bed was of hard clay, which glistened in the sun. . . .

As we came in sight of the next valley, we could see a lake of water some distance south of our western course. . . . This valley we now crossed seemed to come to an end about ten miles to the north of us. To the south it widened out, enclosing the lake spoken of. This valley was very sandy and hard to walk over. When about halfway across we saw some ox tracks leading toward the lake, and in the hope we might find the water drinkable we turned off at right angles to our course and went that way also. Long before we reached the water of the lake, the bottom became a thin slimy mud, which was very hard on our moccasins. When we reached the water we found it to be of a wine color, and so strongly alkaline as to feel slippery to the touch.

We now turned west again, making for a canyon, up which we passed in the hope we should at some turn find a little basin of rain water in some rock. We traveled in it miles and miles, and our mouths became so dry we had to put a bullet or a small smooth stone in and chew it and turn it around with the tongue to induce a flow of saliva. If we saw a spear of green grass on the north side of a rock, it was quickly pulled and eaten to obtain the little moisture it contained. . . .

. . . .

Nothing human is of long duration. Men and their deeds are obliterated, the race itself fades; but Nature goes calmly on with her projects. She works not for man's enjoyment, but for her own satisfaction and her own glory. She made the fat lands of the earth with all their fruits and flowers and foliage; and with no less care she made the desert with its sands and cacti. She intended that each should remain as she made it. When the locust swarm has passed, the flowers and grasses will return to the valley; when man is gone, the sand and the heat will come back to the desert. The desolation of the kingdom will live again, and down in the Bottom of the Bowl the opalescent mirage will waver skyward on wings of light, serene in its solitude, though no human eye sees nor human tongue speaks its loveliness.[1]

The Influence of Terrain on Warfare

Land forms have played important parts in military strategy. The cuestas of eastern France, presenting steep scarps eastward and gentle slopes toward the west, were a great obstacle to the invading German armies and by the same token an invaluable defense to the French. The feats of Hannibal and Napoleon in overcoming the mighty barrier of the Alps have become famous.

---

[1] Van Dyke, 1901, p. 62.

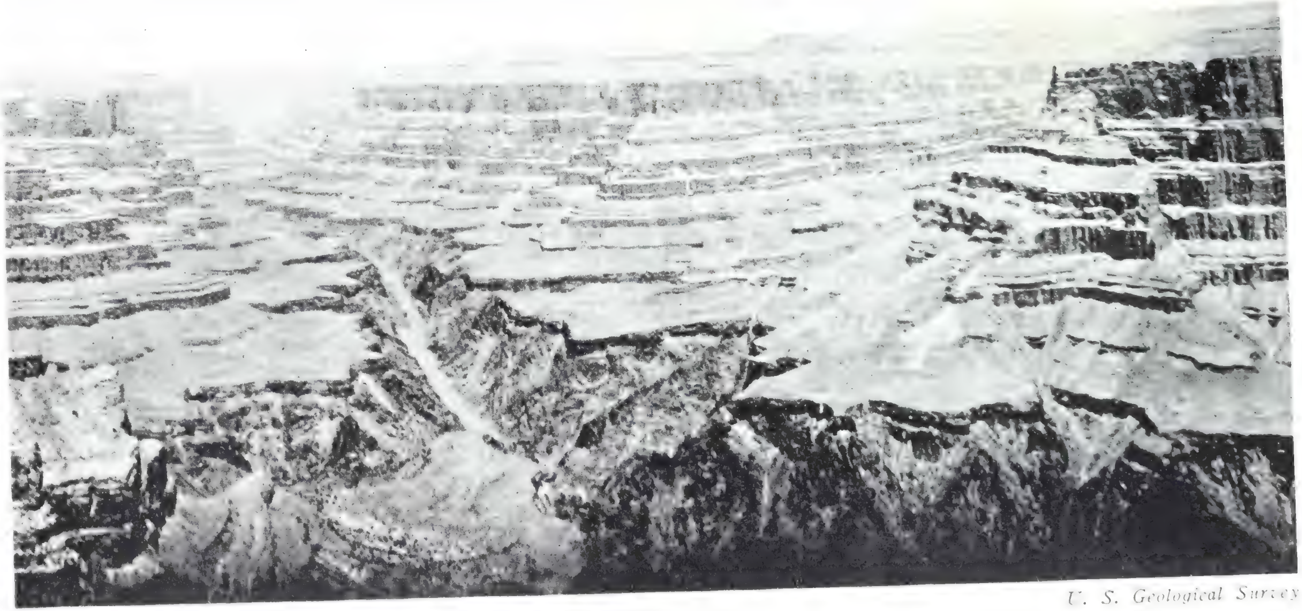
Four accounts are quoted below (Johnson, 1921, pp. 25-28, 59-60, 488-492; Wrigley, 1918, pp. 48-51) to illustrate the kinds of warfare imposed on combatants in the World War by three different types of terrain. The first two deal with the low clay plain of Flanders, the third with the Trentine Alps, and the fourth with arid Southwest Africa.

The Rivers of the Clay Plain

Mud is not the only enemy of an army condemned to operate on the clay plain. Although the rainfall is moderate and notably less than that on the arid chalk uplands of Artois, we have seen that it is held at the surface by the impervious clay and cannot escape rapidly from so flat a region. This excess of water makes trouble in numberless ways. Where it flows into the sluggish rivers they are flooded, for with their faint gradients they cannot rapidly discharge the large total volumes thus received. When they rise, their flood waters spread far and wide, because the country is so low and flat. Almost all the streams of the plain, from the smallest rivulet to larger rivers like the Lys, have one or more floods every year, especially in the late summer or fall and in the early winter. Half a dozen floods in the same stream in a single year are not unusual. In 1882 the Yser overflowed its banks fourteen times. The floods of the Lys are the most dangerous of all in the Flemish plain, and the river has not inaptly been called "the scourge of Flanders." The rising waters not only submerge its broad, shallow valley and flood the city of Ghent, but force the Scheldt to back up and overflow its banks, fill the Bruges-Ghent canal to overflowing, and interfere with the régime of other canals connecting with its valley.

Elaborate works have been undertaken to control the rivers. Many have been straightened and canalized, their rising waters are held in by dikes, their great breadth has often been reduced to a narrow channel, and the extensive marshes bordering their courses have been partly reclaimed. Yet even today disastrous floods are not unknown, and the marshes are still numerous. Where marsh and forest combine, as at Plœgsteert Wood in wet weather, the obstacle is peculiarly formidable and can only be threaded on wooden footbridges, or *passerelles,* raised above the morass. The river channels are barriers which armies may pass only with the aid of bridges, while the valley floors can be flooded by opening the dikes and the difficulty of passage thus greatly augmented. . . .

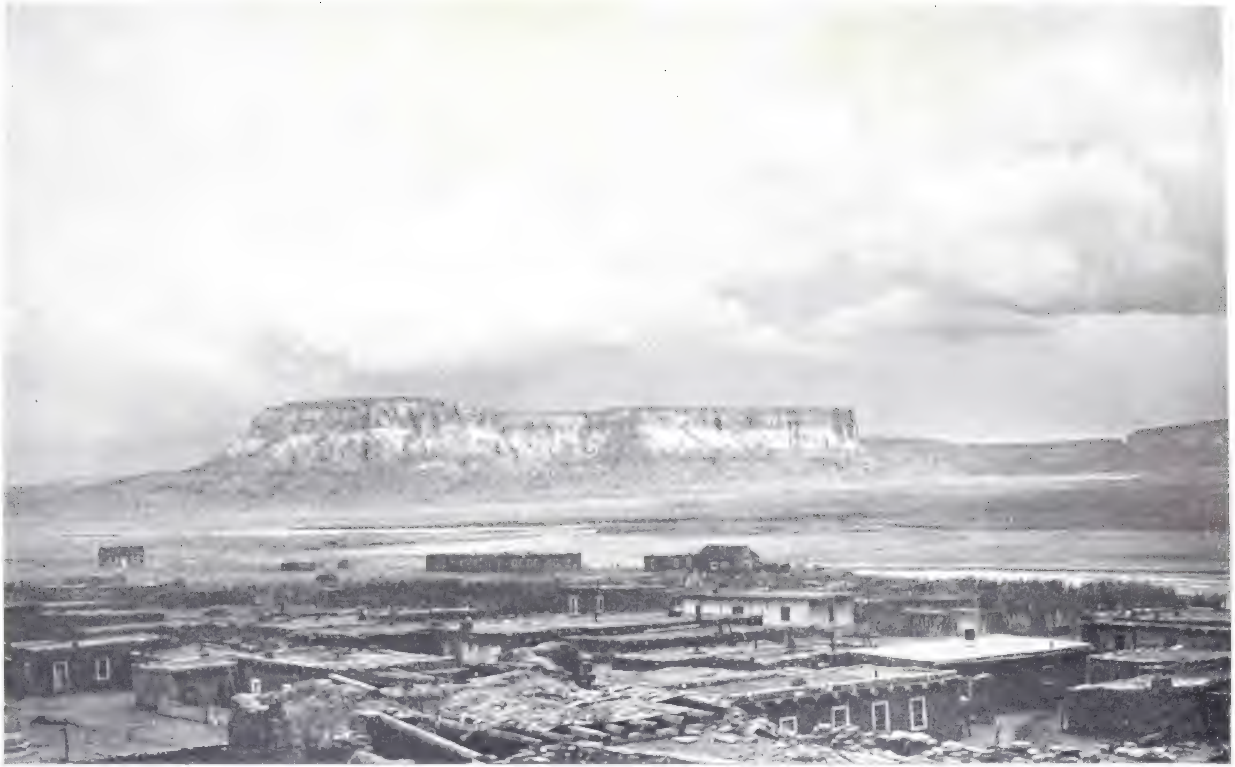
The tactical and strategic value of the rivers of Flanders cannot be doubted by one who reads even a few pages of the long military history of this region. Froissart's "Chroniques" contain many references to the line of the Lys, among them the detailed and quaint description of how in the latter part of the fourteenth century Philip van Artevelde commanded the destruction of all bridges over the river on a front of fifty miles or more, in order that it should be "not in the power of the King of France nor of his Frenchmen, that they should pass the river of the Lis." The advisers of the French king held the barrier in profound respect, and when asked, "This river of the Lis, is it so evil to pass that one cannot find passage save at the well-known crossings?" one of them replied, "Sire, yes; there is no ford, and the stream flows upon marshes which one cannot traverse." Some advised ascending the river until the French army could pass around its source, others counseled turning northeast into another part of Flanders where the advance would be blocked by no such obstacle. Bolder spirits urged an attack on the river barrier, assuring the others that God would aid them to make a crossing; and their advice prevailed. But so difficult did the task prove that even those who urged the attack repented that they had not taken the long route round the river sources or marched in some other direction across an easier terrain. When success was finally achieved, it was by means of a surprise crossing effected secretly with small boats at a poorly guarded point. In the succeeding pages of the "Chroniques" one reads the



U. S. Geological Survey

THE GRAND CANYON OF THE COLORADO

Showing the *Granite Gorge* formed where the river has cut through the weak horizontal sedimentary rocks into the resistant crystalline rocks below.



National Geographic Society

TAHALONE MESA

In the Zuñi Basin, western New Mexico. Remnant of a plateau, capped by horizontal strata.

same complaints of marsh and mud, the same references to soldiers standing knee-deep in the mire, which became so familiar in the despatches of 1914-1918. If we turn to the wars of the French Revolution, we find the Allied Armies holding the line of the Lys early in 1794, then fleeing in disorder when the French capture a section of the barrier. Next it is the French who make the line of the Lys their position, advancing from and returning to it with the exigencies of the campaign. In the disastrous Allied offensive in May, known as the Battle of Tourcoing, Clerfayt's corps, one-fourth of the whole army, was held up by the French standing behind the Lys at Wervicq and so counted for nothing in the first day's operations. Two other columns were held up at the Marque, "a stream impassable except by bridges, owing to soft bottom and swampy banks." In the preceding year the line of the Yser at Bambecque was held so effectively by the Allies that ten times their number of Frenchmen were unable to dislodge them by direct attacks; while the line of the Yser-Ypres canal from Nieuport to Ypres, which was to figure so largely in the World War of 1914-1918, served as the main defensive position of the Allied armies' right wing in 1794.

It is unnecessary to multiply instances in which the rivers of Flanders have in the past served as natural lines of defense. In the recent war the Lys again played an important defensive rôle, the Yser blocked some of the greatest offensives launched by the Germans, while other streams, including so small an example as Kemmel Brook, contributed in no small degree to the results of operations in the clay plain. Rivers and canals combined with the mud of the plain to oppose a serious obstacle to one of the most effective of modern offensive weapons. In most parts of the clay plain it was practically impossible to use tanks; in others, especially in more sandy and less humid areas, they were utilized, sometimes by equipping them with fascines of wood which could be dropped in front as the tanks advanced. But, notwithstanding this device to improve the terrain over which they moved, the work of the tanks on the low plain was never so effective as on the chalk uplands farther south. As for cavalry, military writers have from the earliest times pictured the difficulties occasioned that arm of the service by the endless network of small drainage ditches, the marshes, the larger canals, and the rivers. Artillery and even infantry find the drainage ditches an obstacle which forces them to keep to the roads or to the larger dikes of rivers and principal canals.

Battle of the Yser

On October 16 the Battle of the Yser began. The Belgians were forced to yield ground under a furious German attack.

The defenders [i.e., the Belgians], hopelessly outnumbered and reduced to a state of extreme exhaustion, lacking reserves, and faced with a shortage of munitions, now required all the aid that the natural advantages of their position could give them. "The key of the position was not at Dixmude, nor at Pervyse, nor at Ramscappelle, nor at Ypres; but in the pocket of the chief hydrographic officer who guarded the locks at Nieuport."

A council of war on October 25 decided to flood all the Yser region east of the railway embankment forming the third line of resistance. Accordingly all aqueducts through the embankment were sealed up, and the sluices of Nieuport were opened when the tide was high in order to let in the sea, and closed when the tide was low to prevent the accumulating river, rain, and marine waters from escaping. It was none too early, for on the 26th the Germans in irresistible numbers drove the Allies from behind the Beverdyk, compelling them to seek protection behind the railway embankment. But the terrible strain of continual assaults through mire and water, over rivers, canals, and ditches, was beginning to tell on the invaders. As they paused for breath, the new ally of the Allies made its appearance. About the 28th the Germans discovered that water was rising in the ditches and beginning to flow over the flat land. The peril was imminent, and on the 29th they began a new series of furious attacks, hoping to break through before it should be forever too late. Their only hope lay in capturing the Nieuport buttress, containing the engineering works by which alone the floods could be controlled. But this strong position, supported by the Allied flotilla off the coast, defied every assault. Just to the east the gray-clad invaders, struggling through the mire and the rising waters, "hideous, drenched to the waist, and smeared with mud to the tops of their heads," stormed the railway embankment and entered Ramscappelle. They maintained themselves in the village for a brief space but were soon thrown back. Elsewhere the line held.

The waters continued to rise. Soon from the Dixmude-Nieuport railway embankment the Allied defenders looked out across a flood two or three miles wide, covered with debris and swollen German corpses, which effectively blocked the Kaiser's frantic drive toward the Channel ports. The Teutonic hordes were faced by a liquid trap which yawned to engulf them. Beneath the muddy waters were hidden ditches and canals into which men would suddenly plunge over their heads, and bottomless mud which would hold them fast in the flood. The level surface of the liquid could offer no shelter from the fire of sharpshooter and machine gunner, and those who fell wounded must drown where they dropped. Numerical superiority and Prussian discipline were alike helpless before such a barrier. The Germans retired northward beyond the flood, abandoning quantities of arms and ammunition. And while they might later seize the ruins of Dixmude north of the river, the barrier itself was absolutely impregnable. The Battle of the Yser was over.

The Battlefield of the Trentino

The Trentine Alps consist of complex masses of rocks intensely folded and broken and deeply dissected by stream erosion. Because the rock masses were raised more than

10,000 feet above sea level in their higher parts, streams cut remarkably deep canyons, giving a wild, mountainous country most difficult to traverse. The difficulties were increased many fold when the ice streams of the glacial period flowed down the valleys, cutting them much deeper, steepening the valley walls into rocky precipices, leaving the side valleys hanging hundreds of feet above the floors of the overdeepened main valleys, sharpening the intervalley ridges into knife-edge arêtes, and carving the dome-shaped peaks into jagged needles and horns. The resulting topography is one of indescribable ruggedness, in which precipitous cliffs, inaccessible peaks, steep-sided divides, and hanging valleys present to the engineer almost insurmountable obstacles. Even in time of peace man makes his way across this mighty Alpine barrier only by means of highways which zigzag dizzily over lofty ridges and railroads which rise by devious looped detours into side valleys or through tunnels cut in the solid rock, to reach the few practicable passes.

It requires no great imaginative power to realize that to make war in such a region must tax to the utmost the ingenuity of man. And yet for a variety of reasons, both political and military, the Trentine Alps were destined to become one of the two main battlefields of the Austro-Italian front. The Italian army engineers, worthy successors of the Romans in the art of road construction, built magnificent highways to apparently inaccessible points, over which autocamions could speed swiftly to the battle front on the peaks, bearing their burdens of men, munitions, and material. If a precipice barred the path, the indomitable workmen blasted their way into it and by a system of tunnels scaled the barrier. All along the Alpine battle line there soon appeared a system of these remarkable roads which made it possible to supply armies and carry on campaigns in a region seemingly designed by Nature to separate peoples by an impassable wall.

In regions where not even the genius of the Italian engineer could carry roads, the *teleferica,* or aerial tram, raised men and provisions, guns and munitions, to battle grounds among the clouds and lowered the wounded to hospitals in the valleys far below. On the lofty Adamello six successive hoists by as many *teleferica* lines raised the Italian soldier between 3,000 and 4,000 feet to the reserve positions behind the main front line; and, when Monte Grappa became the mountain buttress of the Piave front, great numbers of these aerial cables were used to aid the roads in supplying troops on that important height. Between *teleferica* stations tramways drawn by mules sometimes traversed the high mountain valleys, and, where snow fields and glaciers lay along the spectacular battle ground, dog sleds formed the line of communications, either across the surface or through tunnels several miles long in the ice, according to the degree of exposure to enemy fire. Assuredly this is the terrain *par excellence* of "mountain warfare".

Nor would the story of the adaptation of methods of warfare to this mountainous country be complete, even had we covered fully the question of communication lines. Big guns with specially devised wheels which facilitated the ascent of very steep slopes; sandbag breastworks or stone walls replacing trenches where impossible to excavate the latter in the solid rock; white uniforms for portions of the front on snow fields; Alpine troops on skis carrying ice axes and alpenstocks as essential parts of their equipment; electric motor lorries with trolleys driven up the steepest road by power derived from local mountain torrents—these are but a few of the responses which the contestants on one side or the other made to the special physical conditions which confronted them on the Alpine front. The flying corps had to contend with vast stretches of country affording no suitable landing place and with the treacherous air currents peculiarly frequent above such rugged terrains. The supplying of water to the troops engaged on high mountain ridges and plateaus of fissured limestone presented a series of complex problems which became acute whenever an advance was attempted. These problems were solved by the construction of great aqueducts and pumping plants, by the laying of miles of pipe lines leading to the stationary sectors, and by the organization of trains of pack animals to distribute the precious fluid to the most inaccessible portions of the field as rapidly as the front was pushed forward in any given sector. Men and mules were lost in crevasses in the glaciers. Avalanches, some starting from natural causes, many dislodged by heavy artillery fire, swept down upon helpless troops, a single battalion advancing to attack losing forty of its number in this manner.

Such was the warfare along the northern Italian frontier, and such the terrain upon which it was waged. An observer looking over the wild waste of Alpine crags from some lofty summit or gazing down upon the white-cupped waves of the frozen granite sea from some soaring airplane would scarcely imagine that armies could find footing in the wilderness of ice and rock, much less fight battles there. Yet through the maze of peaks and ridges there pass narrow runways which were threaded by migrating hordes before the dawn of history, corridors along which invading armies advanced and retreated as the walls echoed the din of early battles. Roman legions conquered the mountain fastnesses and passed beyond to subdue the lands to the north. In later centuries rude invaders from the north repeatedly reached the sunny south through these same mountains. Napoleon's armies marched and counter-marched from victory to victory in this forbidding realm, as well as on the open plains of other lands. Clearly there must be, either in the terrain itself or in its position with respect to other lands, or perhaps in both, something which made of it one of the predestined battlefields of Europe.

The Military Campaigns Against Germany's African Colonies

. . . In the Peruvo-Chilean war the first step towards conquest of the desert lay in securing control of the sea highway of communication. When the Peruvian fleet had been defeated, Chile gained the seaboard, and the fate of the campaign was decided. In the Southwest African desert control of the seaboard was likewise of vital importance. It was essential that Swakopmund and Lüderitzbucht should be occupied as bases and the sea highway to the Cape be maintained. Apart from retaliation to the German attack on the Orange River and the subsequent unfortunate affair of outposts, the first British move was to recapture Walvis Bay, seized by the enemy on the declaration of hostilities, and to occupy Lüderitzbucht. Before further advantage could be taken operations were, however, suspended for a time. The revolution within the Union successfully stimulated by Germany in the main accounted for the delay, but a contributory cause was the temporary disturbance of British sea power occasioned by von Spee's attack off Chile. The battle of the Falklands was necessary to restore confidence in the southern seas.

The real offensive against the colony began early in 1915. A northern and major column under General Botha started from Walvis Bay and Swakopmund. In the south three main columns invaded the colony simultaneously; one proceeded from Lüderitzbucht, and another, in three sections, from the Orange River. The third, having Kimberley as base, crossed the Kalahari Desert and entered German territory from Rietfontein. These three columns planned to unite at some point on the railroad near the junction of Keetmanshoop, thence to proceed on Windhuk from the south as Botha's column advanced from the west.

The hardships of the northern column began with the landing at Walvis Bay, of which the personal narratives paint unattractive pictures. The natural harbor is excellent, but landing facilities were undeveloped. All other native resources are lacking, and the climate is peculiarly disagreeable. The order of the day was "humidity, fog, and cold each morning, atrocious wind every afternoon and evening". Although situated within the tropics this portion of the coast is swept by the cold Benguela Current, which, like the Humboldt Current on the corresponding shores of South America, lowers the temperature and is in part responsible for the characteristic fog belt that hangs over these coasts. Although the air is humid, rain is practically unknown, and except on rare occasions the river beds are dry. An unusual phenomenon that might have been regarded as a happy augury greeted the arrival of the commander in chief; the Swakop River came down in flood and flowed for a day after Botha's entry into Swakopmund. It was the first time for some fifteen years that the river had reached the sea, and it swept away the railroad built across the flats of the river mouth. But the flood was hailed as a promise of unusually favorable conditions in a region where the water supply is the ever-present question. From their landing the forces were faced by this question. Walvis Bay is absolutely dependent for its water on sea-water distilleries of limited capacity, and at first water had to be brought from the Cape, 800 miles away. On the march inland the troops mainly depended on the water holes in the Swakop River. The holes and wells, carefully charted on the maps, are generally nuclei of tiny settlements. Round the most important of them was fought the sharpest and most decisive action of the campaign —the Pforte-Riet-Jakalswater engagement. Advance was made up the river bed and by the reconstructed railroads. Across the desert belt impediment to transport was peculiarly great, the highly micaceous sand causing wheeled vehicles the greatest trouble. Success indeed depended on the mobile army's ability to surmount difficulties of transport. Arid sand and bare rock contributed a curious feature to the campaign. The blasting necessary in sinking for water requires the use of enormous quantities of explosives; every farm had its own stock of dynamite. The German forces could thus draw on vast stores, and they took full advantage of their opportunity. The degree to which the roads were mined is a marvel only exceeded by the singular failure of the scheme.

The difficulties of the northern column were fully shared by their co-operators in the south. They, too, faced lack of water, poisoned wells, scant grass, and absence of native resources. Even the cattle had been moved from the grazing grounds. In one instance the force crossing the Kalahari on its 600-mile march from Kimberley found itself 120 miles from the next water site. The problem of supply was solved by establishing two intermediate stations to which water could be carried by motor over these 40-mile jumps. The column from Lüderitzbucht had the advantage of the railroad, but even the iron line has to pay the toll of the desert. In the Grasplatz section of traveling dunes some hundreds of laborers must be kept constantly employed clearing the line, an item of upkeep said to have cost the German government about $50,000 a year.

BIBLIOGRAPHY

Chapter XII—Land Forms

W. M. Davis, *Methods and Models in Geographical Teaching.* American Naturalist, vol. 23, 1889, pp. 570-574.

J. S. Douglas, Superintendent of the San Emigdio Ranch, quoted by Eliot Blackwelder in *The Mudflow as a Geologic Agent in Semiarid Mountains,* Bulletin of the Geological Society of America, vol. 39, 1928, p. 470.

Herbert Clark Hoover and Lou Henry Hoover, Georgius Agricola's *De re metallica,* 1912, Appendix A, pp. 595-596.

D. W. Johnson, *Battlefields of the World War.* American Geographical Society Research Series No. 3, 1921, pp. 25-28, 59-60, 488-492.

Eliot Lord, *Comstock Mining and Miners.* U. S. Geological Survey, Monograph 4, 1883, pp. 4-5.

William L. Manly, *Death Valley in '49.* Chicago: R. R. Donnelley & Sons Company, 1927, pp. 138 ff.

J. W. Powell, *Exploration of the Colorado River of the West and Its Tributaries.* Washington: 1875, pp. 6-7, 8-9, 14, 78-79, 80, 88-89, 103, 152-153, 163, 165-166, 171-172, 213-214.

John C. Van Dyke, *The Desert.* New York: Scribner's, 1901, pp. 16-17, 23-26, 30-32, 32-34, 62.

Bailey Willis, *The Northern Appalachians* (in *The Physiography of the United States*). National Geographic Society, New York: American Book Company, 1896, pp. 188-190.

G. M. Wrigley, *The Military Campaign Against Germany's African Colonies.* Geographical Review, vol. 5, 1918, pp. 48-51.

CHAPTER XIII

GEOLOGY IN MODERN LIFE

The popular caricature of a geologist, a stooped figure in a baggy suit, halting his course over the hills merely to pick up a piece of stone or an ancient bone and intent only upon acquiring knowledge useless to man, will probably always persist. But science has proved so often that it can increase our comfort and add to the money in our pockets that it cannot be lightly scorned. There are many, of course, who pursue learning for the sheer pleasure that it yields: to these science (and geology is not exempt) is an end in itself. But we are rapidly learning that our growing knowledge of the Earth can be applied in ways unsuspected even fifty years ago.

We live in an age that demands metals, oil, coal, clay, and many other substances. Increasing knowledge has not lessened man's dependence on the Earth; it has merely taught him better how and where to find what he requires. No longer does the miner seek blindly for ore by rule-of-thumb methods, acquired perhaps in a very different region; and the catch-phrase "bet against the geologist" has largely disappeared from even the boom mining town and the new oil field.

There are good reasons for this change. Unless one lives in an outpost of civilization, in one of those fast-shrinking frontier areas that few men have seen, he has little chance of finding gold-bearing sands or outcropping ledges ripe for picking. The evident things are mostly known and exploited. The great bonanzas of the world have filled man's coffers, and a new knowledge is needed to win the remaining treasure from the Earth's rocky crust.

There is another new and growing contact between geology and the everyday work of the world. A short while ago the civil engineer, if he considered them necessary, made his own geological interpretations. But bridges are heavier now than they used to be, and they need firmer foundations; dams are higher, and they impound more water. To be sure, there are few of the natural obstacles to construction that an ingenious engineer cannot overcome if sufficient money is available, but the cost of mistakes is high, and a little special knowledge gained beforehand saves much time and many regrets.

All the branches of geology have their economic application and may be called upon at any time to furnish evidence upon which important litigations are decided. The contacts that arise with human affairs are frequently unexpected and sometimes amusing.

Geology and Mining

The oldest use of geology is in finding and working mineral deposits. The geologist must study the origin and distribution of mineral deposits, estimate reserves and value mineral properties for purposes of taxation. Many theories concerning the ores —where they came from and how they got where they are— theories rooted deep in the abstract studies of the past, are bearing fruit; and mines that would otherwise have been abandoned increase their yield.

The laws relating to mineral resources are extremely difficult to interpret. The very nature of mineral-bearing masses and our uncertainty regarding them make it impossible to define their form and relations with the degree of accuracy required by an inflexible law. The clash of interests results in a demand for geological evidence and expert interpretation.

Mining Law

The sources of American mining law are found in the principles of the common law of England, and in the laws of the various states and territories. Contributions have been made in the form of laws enacted by Congress to apply to those areas that originally belonged to the Federal Government.

All of the vast territory that stretches from the front ranges of the Rocky Mountains to the shores of the Pacific Ocean, together with the whole of Alaska, fall into this last category. This region includes the major part of the mineral wealth of the nation. Within it, the Federal statutes are the most important though not the sole source of mining law.

These statutes, differing from all previous laws in this or other countries, must be briefly outlined. They originated among the "Forty-niners," the pioneers who descended in hordes upon the rich western slopes of the Sierra Nevada. Charles H. Shamel (1907, pp. 91-92) says in his book on Mining Law:

Development of a "Common Law" of Mining in California

Gold was discovered in California in January, 1848, the province being then held by the United States by right of conquest, which was afterward ratified by the treaty of Guadalupe Hidalgo, proclaimed July 4, 1848. Then immediately began the historical rush of gold-hunters whose unparalleled success in finding the precious metal poured into the channels of commerce of the United States and of the world a flood of gold that has produced profound industrial and political effects.

But all the hunting and digging of this stupendous treasure was done without any direct sanction of law until 1866, before which year all of the richer placer deposits had been exhausted and much gold had been mined out of the Mother Lode. During all of this time prospectors and miners were technically trespassers upon the public land belonging to the United States, and there were absolutely no statutory or even common-law principles or rules to define and guide mining and mining rights. But this strenuous activity in seeking and mining gold could not be conducted without some kind of law other than the primitive rule of "might makes right." Very early the miners, realizing this, made laws for themselves in the shape of rules, regulations, and customs governing the digging of gold in the various districts. Though these rules and customs differed somewhat in the different districts as to details, there were general features common to all. Two of these are of special importance as they were substantially incorporated in the United States mining laws enacted later. They were: (1) discovery and working gave right to the mineral; and (2) in the case of mineral found in veins, the discoverer had the right to pursue his vein to any depth although it conducted him under the surface of another claim.

> The system which grew up regulating mining operations was a true example of the development of a "common law" from custom. . . .

The first act of Congress that gave the miner an absolute title to his land was passed in 1866. But this act was vague. The vein or lode was the thing claimed and acquired by patent. If this was found underground in the course of a tunnel, the miner acquired a certain length along it whether his surface claim included it or not. He did not own the surface at all, but had only a right to occupy it with shafts, dumps, etc.

In 1872 the present or "apex" law came into being and with it all the possibilities for lawsuits arising from the vagaries of Nature and man's cupidity. This law gave the claimant the right to the surface within his claim and to all veins that outcropped ("apexed") therein. Everything on or below the claim belonged to him with one special and important extension and corresponding restriction: Under certain circumstances he could follow a vein down its dip from his bit of surface even if it led below the surface owned by another. Under similar conditions the owner of a neighboring claim could invade his territory. This last provision grants what are known as "extralateral rights."

The law is clear enough, but it contemplates a special case that rarely occurs; a well-defined vein or lode or a series of parallel ones that do not vary in dip or in their course along the surface and have no offshoots nor connecting veins.

It is probably impossible to enact a law that will not work hardship on someone at some time. In other lands the nearly universal law gives the owner of a claim the right to all that lies vertically beneath his land. This would seem clear and just enough; but, as Shamel (1907, p. 99) points out:

> . . . there is an inherent injustice in the idea that the miner who has had the courage to spend his time and money and develop a valuable mine by following a vein, it may be, hundreds or thousands of feet before he finds enough mineral to return his expenditure should lose the benefit of his endeavors by the vein going on the incline outside the boundaries of his claim into the territory of a person who has located the

adjoining ground and then simply stood aside and waited for the others to determine whether or not mineral existed in the vein in paying quantities.

The law of the United States has this advantage: it was developed from the desires of the miners themselves; it was what they wanted. But the trouble is that few veins are straight, and few dip uniformly. Instead, they cross each other, they split, they disappear, and they pinch out to thin seams only to swell again. The law itself is clear enough: for instance, when many deep veins unite to form a single one, the prior location takes all below the junction including the area of junction; when two veins cross, the prior location takes all included in the intersection. But there are always points of fact to be decided. What is a vein? Is a split a part of one vein or of another? Is vein *C* a continuation of *A* or of *B*? These and numberless other facts can be decided only upon geological evidence, and they tax the powers of observation of the most acute. Thus geology forms the basis for the interpretation of the law which, in turn, has caused the discovery, under necessity, of much that is of value to geology.

Placer Claims

A placer claim is very different from a lode claim. Placer claims may be located on land valuable for mineral deposits not in place —that is, gravel and sand beds containing gold, platinum, precious stones, etc.—and upon areas valuable chiefly for building stone or underlain by salt, gypsum, oil, or natural gas. Such claims may be larger than lode claims, but they grant no extralateral rights; that is, they give to the owner only the right to the mineral matter that lies vertically beneath the claim.

The distinction appears clear enough, but what happens when a lode or a vein lies horizontally like an undisturbed stratum of rock? Shamel (1907, pp. 233-236) cites the following case:

Horizontal Veins

As we have before remarked, the theory of the statute seems to be that mineral deposits are found in veins or lodes which extend downward in directions which depart more or less from the perpendicular, but which neither closely approach nor become horizontal. The case of a vein which is horizontal was apparently not in the mind of the legislators, and, indeed, it is probable that at the date of the passage of the statute of 1872 no instance was known of a vein which assumed a horizontal or even an approximately horizontal direction. However, in 1879 the question of veins in such situations came prominently before the courts on account of the discovery of the great ore deposits of Leadville, Colo. Here silver ore was found in connection with iron-impregnated strata which were frequently horizontal or very nearly horizontal in direction. . . .

There was a very strong local feeling in the district against allowing extralateral rights to the fortunate claims which were located on the outcrop of the vein. It was contended by the miners that these deposits were not included in the veins or lodes granted extralateral rights by the statute. It is stated that this feeling was so strong that it was impossible for the owners of the apexes of these deposits to gain their rights in the courts by means of a jury trial. For, although the law might be correctly stated in the instructions, the jury would nevertheless decide that the ore-body in dispute in the particular case was not a vein or lode, and consequently deprive it of extralateral rights. At first, the lower courts took the position that, if the vein was exactly horizontal, no extralateral rights would accrue to such vein, but that it must be governed by the provisions relating to placer claims. The court says, in the case of *Stevens* vs. *Williams,* 1 McCrary, 480 Fed. Cas., 13,413: "If there is any departure from a horizontal position it is sufficient" [to give extralateral rights]. Again, in *Leadville Co.* vs. *Fitzgerald,* 4 Morr. Min. Rep., 38, Fed. Cas., 8158, the same court says: "It is conceded that if the vein be exactly upon the plane of the horizon it is not within the Act."

But when the final authority, the United States Supreme Court, came to pass upon this question which arose in the case of *Iron-Silver, etc., Co.* vs. *Mike & Starr Co.*, 143 U. S., 394, they took the opposite view, saying:

> "and as to the other matter, that the title to portions of this horizontal vein or deposit, 'blanket' vein as it is generally called, may be acquired under the sections concerning veins, lodes, etc. The fact that so many patents have been obtained under these sections, and that so many applications for patents are still pending, is a strong reason against a new and contrary ruling."

And this is now the law with regard to horizontal veins.

Rule.—Flatness or absence of dip in any vein does not affect the extralateral rights belonging to the same. Extralateral rights accrue to a horizontal or approximately horizontal and to a bedded or blanket vein as well as to veins having larger dip angles.

The Comstock Lode

The famous Comstock Lode in western Nevada rises from the depths as a single vein, and then splits into many branches "apexing" at different levels along the mountain flank. The early miners located their claims in the belief that these were all separate, parallel veins. Now prospectors, being canny individuals, will not record a claim until they are reasonably sure that they do not want to shift their lines. These mixed claims, combined with the lack of a definite law before 1872, gave rise immediately to many conflicts. A little later the company working the prior claim conceived the idea that the many veins might unite in depth—in other words, they might be free to take everything left in the lode—as soon in fact, as the veins, ever drawing closer, should unite. Then there arose a series of disputes worse perhaps than those in any other "bonanza" town. The courts, hastily set up, became centers of intrigue and bribery and the meeting places of armed men instead of places of peaceful arbitration. Eliot Lord has written a monograph on the Comstock mines and miners in which he portrays vividly the character and discovery of the region, its development, and the conflicts that

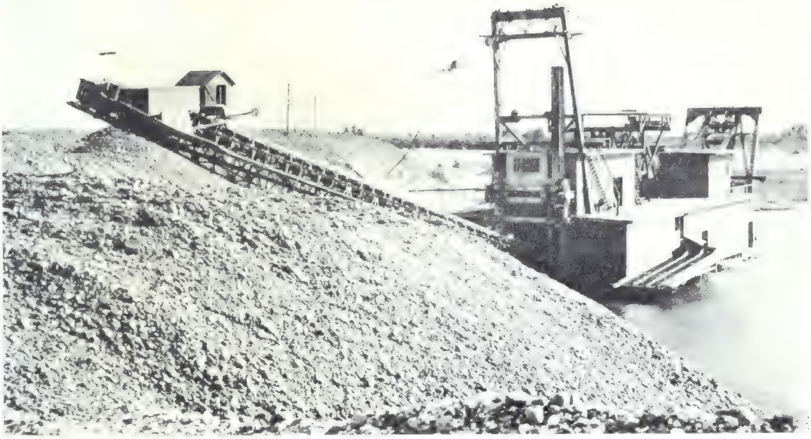
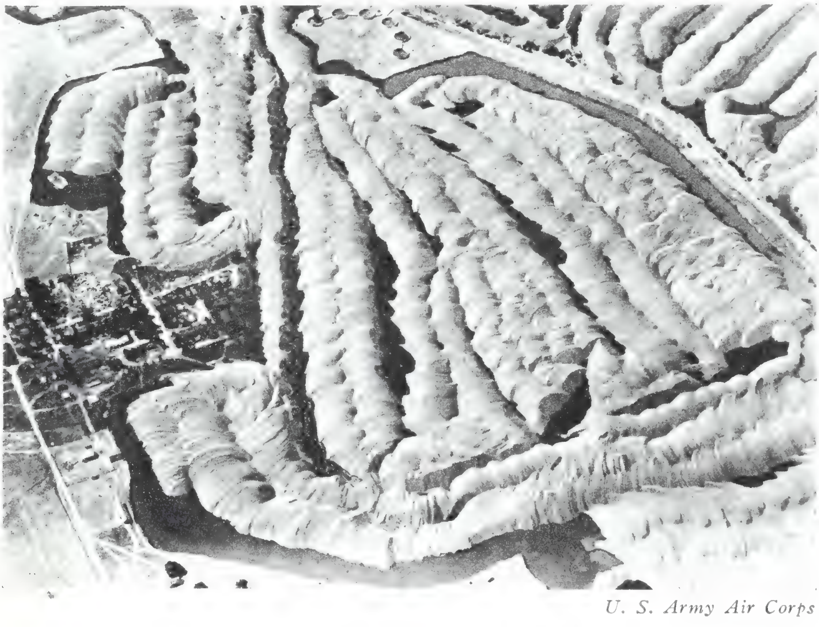


Photo W. C. Mendenhall

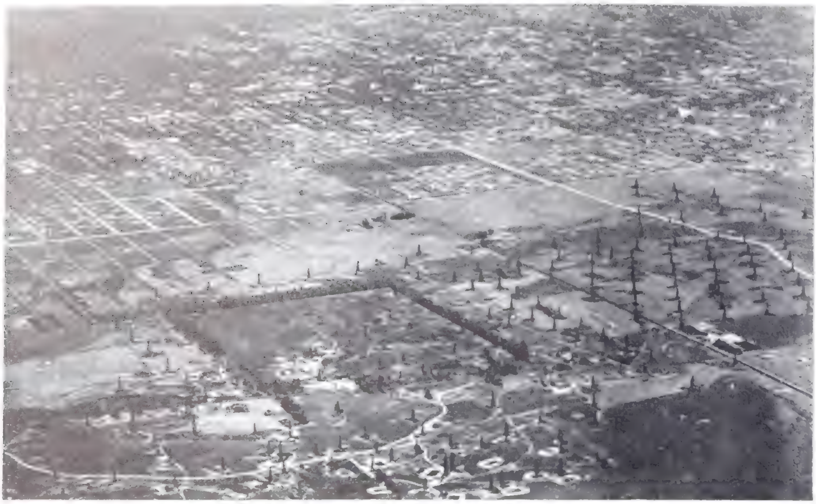
A. A GOLD DREDGE AT WORK IN THE SACRAMENTO VALLEY, CALIFORNIA



U. S. Army Air Corps

B. THE RESULTS OF GOLD DREDGING

The caterpillar-like forms are the waste thrown out by the advancing dredge. Sacramento valley, California.



U. S. Army Air Corps

A. OIL FIELD NEAR HOLLYWOOD, CALIFORNIA

Photo W. C. Mendenhall

B. OIL GUSHER AND RESERVOIR, LAKEVIEW, CALIFORNIA followed. Parts of his account (Lord, 1883, pp. 10-14, 37-40) are reproduced here:

> The first wagon train which entered the valley in the following spring was a noteworthy little caravan. Leaving Salt Lake in April they found fresh pasturage along the banks of the Humboldt River, and their cattle suffered little, though the heavy canvas-topped wagons were dragged slowly over untried track, as the beaten trail was flooded by the swollen river. The party were nearly all Mormons, led by Thomas Orr, still living (1881), a hale, clear-eyed old man, at Duncan's Mills, Sonoma County, California. They were an orderly if somewhat stolid company, obeying orders without questioning why, drawing up their wagons at nightfall in a circle, and sleeping under the eye of their watchman as composedly as sheep about their shepherd. At the sink of the Humboldt, in sight of the snow-capped Sierras, the wall of the promised land, even this cool-tempered, well-fed caravan began to hasten their steps. Some of the youngest and best mounted men rode forward rapidly to make the first trial of the mountain passes, and the main body followed by crossing the 40-Mile desert and ascending the valley of the Carson.
>
> On the 15th day of May they halted for a few hours, at noon, beside a little creek flowing down from the range of hills which bounded the valley on the east. The cattle were turned loose to graze among the sage brush, and the women of the party prepared the simple dinner of bacon and potatoes. William Prouse, a young Mormon, meanwhile picked up a tin milk-pan, and going down to the edge of the creek began washing the surface dirt. After a few minutes he returned and showed his companions a few glittering specks on the bottom of the pan. The specks were gold dust, worth intrinsically only a few cents, thrown carelessly aside a few moments later, but they were then transformed into precious and fruitful seed, for this pinch of dust was positive evidence of the existence of gold in the deserts of Western Utah, and that starting point once

given, the exploration and development of the mineral resources of the land were assured. The visionary prospector would willingly turn his back on the known riches of the Californian plains to wander over the alkaline sloughs and dusty plains of the unknown territory; the wilderness north, east, south, and west would be searched with greedy eyes, and the threads of gold would be traced up the cañon water-courses until the fountain-heads were reached and the hidden treasures of the mountains were brought to light. To the Mormon pioneers, however, the pinch of dust had no such far-reaching significance. They had scarcely heard of quartz mining and saw nothing attractive in the brush-covered hills with their jutting piles of tawny yellow rock—the bones of the land, as a fanciful writer declared, showing through its rags. The creek sands were not rich compared with the Californian plains which their fancy imaged, and they were impatient to reach the El Dorado of their waking dreams. The train moved on therefore, up the valley again, until they met the advance division returning, who had left them at the sink of the Humboldt. The Sierras were reported to be impassable, and the united party accordingly turned back and were perforce content to remain three weeks longer in the valley.

John Orr, the son of the Mormon leader, and several others returned to Gold Creek or Cañon, as they named the ravine where the first signs of gold were found by Prouse, and resumed prospecting. Orr, with one companion, Nicholas Kelly, worked up the cañon rapidly until, on the first day of June, they reached a point where the banks of the rocky ravine approached so near each other that a narrow passage only was left. Through this cleft the water of the creek flowed swiftly, falling over the rocks in tiny cascades. In a crevice at the edge of one of these little falls Orr thrust a butcher's knife and pried off a loose fragment of rock. The running water soon washed out the underlying dirt, and he saw a small golden nugget which the rock had covered. In a moment he held in his hand the first piece of metalliferous quartz from a district which has yielded the great bonanza of the present century. Other bits of goldbearing quartz and gold dust as well were afterward obtained, but the prospectors lacked tools and provisions, and, bent on reaching California, abandoned the cañon and crossed the Sierras as soon as the trail was sufficiently free from snow. But meanwhile other emigrants had entered the valley, and the new placer diggings were fairly opened.

The news of the discovery of gold spreads from prospector to prospector precisely as the discovery of carrion is announced by the flight of vultures and crows. A horseman riding in haste toward some point off the beaten route is an intelligible sign and loadstone. So, for instance, two boys, Wand and Knous, while camping in the valley on the 1st day of August, saw a train of Mexicans plodding over the hills, carrying wooden bowls (*batia*), fashioned from tree trunks, on their backs, and driving small donkeys loaded with provisions and miners' equipments. Following on the trail of this party the boys came up with them at Gold Cañon and found them prospecting industriously. The creek was a mere thread of water, but the Mexicans knew how to whirl the dry placer sand in their bowls till the wind blew off the barren dust and the gold specks could be scraped with horn spoons from the bottom of the batia. Don Ignatio Parades was the leader of the expedition, a troop of peon miners whom he had brought from Alamos, Sonora. He had been guided to the cañon by two native Californian prospectors and found the placer dirt fairly rich in gold. The peons worked contentedly therefore for some weeks, when they were obliged to abandon the placer, owing to the high price of supplies and the difficulties of transportation.

The overland movement during this year (1850) was like the march of an army. On June 18, 39,000 emigrants had been registered at Fort Laramie, and it was estimated that 60,000 had set out to cross the plains by the northern or South Pass route alone. This mighty procession swept off every green thing in its path like a cloud of locusts, and by the month of

August scarcely a blade of grass was to be seen along a stretch of 200 miles, from Martin's Fork to the slough of the Humboldt. For nearly the whole distance the route had become a continuous marsh, in which cattle were miring and dying by the hundreds. Within a radius of fifty miles from Humboldt Lake the country was literally strewn with carcases and the terrible effluvia from the rotting bodies tainted the air for miles around. The price of flour rose in Carson Valley to $1.50 per pound and to $2.50 at the sink of the Humboldt. Relief parties were sent out from the California towns, but the privations of the emigrants and the little mining settlements in the valley became extreme. Work was suspended and the placer deserted until the following year. Thus the continuous existence of a mining camp at Gold Cañon may be said to date from the summer of 1851.

Thus at the time when the Gold Hill placer was beginning to yield rich returns (May, 1859) the miners in the cañon to the north had moved up the ravine until two of their number, Patrick McLaughlin and Peter O'Riley, were washing dirt on the slope of the hill at its head. The earth was so poor that they were fast becoming discouraged and talked of setting out for the diggings on the Walker River, which were then thought to be promising well, but they worked on, hoping to earn enough to purchase the outfit necessary for their proposed venture, and made their trench each day farther up the hill. A little rill of water flowed down the slope toward them, but so slender was the stream that, in order to use it for their rockers, they were obliged to dig a hole in the ground as a reservoir when they had crossed the narrow basin at the head of the cañon and reached the steep side of the Sun Peak. Accordingly, on the 8th of June they began to dig this water-hole a short distance above the cut where they were mining. The earth thrown out carelessly by their shovels was a yellowish sand mixed with bits of quartz and friable black rock, such as they had never seen before. Simply as an experiment they concluded to wash a little of the sand in their rocker, though they had slight hope that it would yield any return. From the trench sand they had been getting only a few specks of gold dust, but when the new earth had been shaken in the rocker and the muddy water had drained away they saw the bottom of the cradle covered with glittering dust. Overjoyed at their good fortune they began to wash hastily the precious earth, and again and again swept up a golden layer. The dust was of a pale yellow color, and the miners supposed that it was alloyed with some base metal, but it was unmistakably gold, and even with their rude cradle they were fast making a fortune.

The line of the great lode had been cut once more, and a modern box of Pandora fairly opened. As usual, however, a loud-spoken trickster contrived to rob the true discoverers of whatever honor is due them. The names of John Orr, Hosea and Allen Grosh, James Finney, Peter O'Riley, and Patrick McLaughlin are almost unknown,—the Comstock lode is famous throughout the world.

How Henry Comstock won his monument and cut the name of an impostor ineffaceably in the rock is briefly told. He was a tall, gaunt Canadian, who had wandered about for many years as a fur-trader and trapper, and at length drifted to Gold Cañon, where he prospected with indifferent success, like most of the miners, until he took up a claim at Gold Hill, . . . after the supposed placer had been marked out by the four discoverers. Always on the watch to avail himself of the exertions of others with as little fatigue to himself as possible, he quickly installed himself in the vacant cabin of the Grosh brothers and managed to hold his productive claim through the labor of two Indians only less lazy than himself. Thus relieved from the irksome necessity of washing sand for a living, he was able to gratify his taste for rambling about aimlessly from point to point, and by chance came riding over the hills in the early evening of the day on which the discovery was made. The two Irishmen were preparing to leave the ground for the night and were cleaning up their rocker for the last time. They had marked in some way by stones or stakes the limits of their claim, and had no reason to suppose that their rights would be disputed. As he approached the water-hole his restless eye caught sight of the earth heap and the rich contents of the rocker. Without a word he sprang from his pony and threw himself on his knees in the hole, running his fingers through the dirt and observing the tiny spangles which clung to his hands. Standing up at length he coolly informed the astonished miners that they were trespassing on his land. A goat might search in vain for food among the crags and crumbling rocks of that barren peak, but Comstock pretended that he had taken up a tract of 160 acres along the slope of the mountain for a ranch, and that the conveniently indefinite boundaries of this tract included the water-hole and trench where the men were working. He was willing, however, to allow them to continue work, if they in turn would recognize his proprietary rights by conceding to his friend Emanuel Penrod and himself an equal share in their claim.

A more preposterous demand could scarcely be made. He had no title to the ground and no record of his ranche location. The land in question was the property of the United States, open by tacit consent for the occupation and use of any citizen. Yet he talked so loud and long that the miners for the sake of peace agreed to his proposal; but not content with this concession to his ridiculous pretensions, he laid claim further to the little stream which the men were using, asserting that it flowed from a spring higher up the hill, which Finney, Penrod, and himself had bought from the first discoverer and claimant. His title to the water was, perhaps, less absurd than his lien upon the land, and he succeeded, at any rate, in carrying his point by obtaining a grant of 100 feet on the line of the rich seam on condition that the right to use the water should be enjoyed by the partners in common. When this question was amicably settled, McLaughlin and O'Riley worked quietly for two days longer, obtaining each day richer returns, while Comstock busied himself in prospecting on the new claim and in making preparation for the meeting which the miners proposed to hold on the 11th of June, near his claim on Gold Hill, in order to frame laws and regulations for a new mining district.

With such a beginning, and with a veritable horde of eager men descending upon the region, few of whom were more particular about the rights of others than Comstock himself, there is little wonder that clashes developed. Before mining had gone very deep, each prospector was sure of the great value of the lode, and wanted all of it that he could get. Some of the means used to gain this end are described by Eliot Lord (1883, pp. 134-137) as follows:

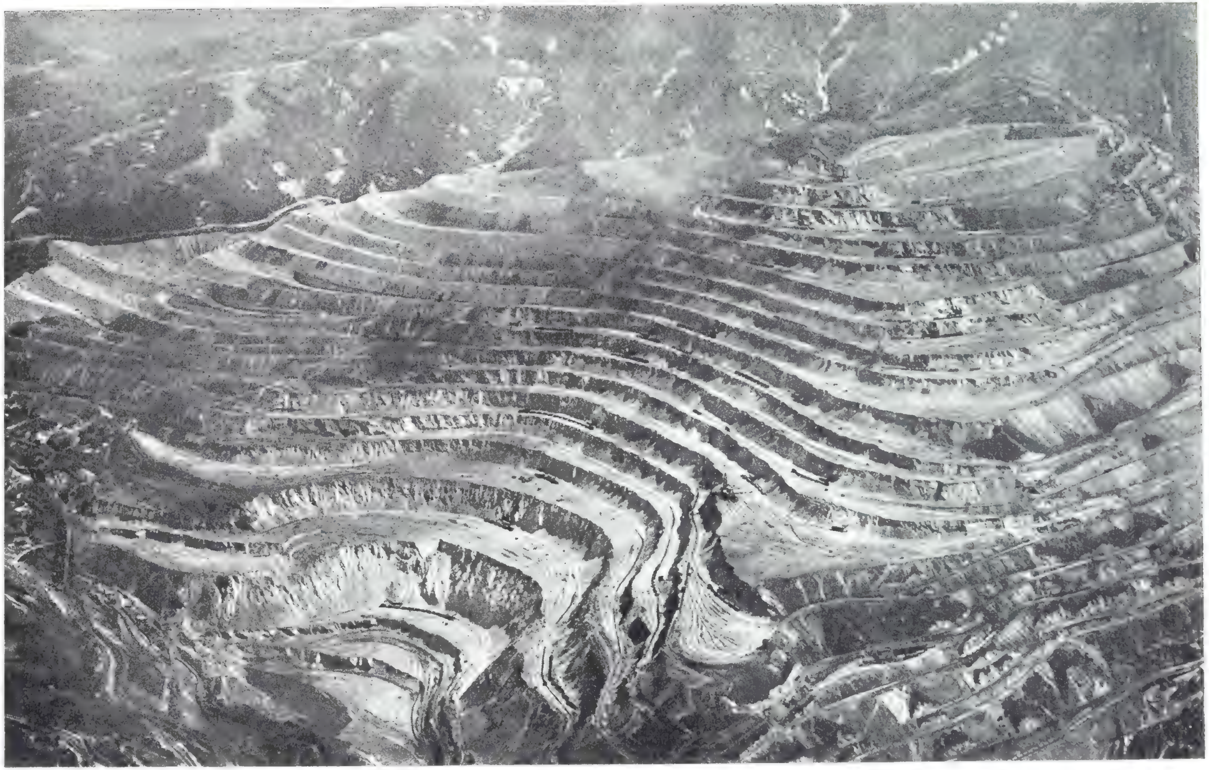
> The cloud of uncertainty which rested on these trials grew blacker and more heavy from month to month. Witnesses were manufactured by wholesale, and testimony to suit the requirements of a case was bought and sold with scarcely a pretense of secrecy. No facts were so clear and well established that they could not be controverted by a troop of hired liars, and the trials became conflicts, in which witnesses were pitted against each other on the ground of numbers rather than of competence or character, for a hundred asseverations of ignorant, prejudiced, and corrupt men were relied upon to outweigh the careful reports of trained observers. In the excitement of the contest each claimant believed his opponent unscrupulous, and under the plea of self-protection was tempted to resort to any method of defense. "We had to fight fire with fire," said a leading lawyer of the Californian bar, and the metaphor needs no exponent. Wealthy Californians who had invested fortunes in these mining claims saw the imminent peril of their savings with a dread which obliterated considerations of abstract morality. Some contented their consciences with taking no active part in the struggle except furnishing the sinews of war, and closed their eyes and ears to the unpleasant sights and sounds beyond the Sierras. Every well-

meaning man washed his hands of the stain as far as this was in his power, and eagerly shook off the burden of responsibility upon less fastidious shoulders, for agents could always be found to carry out a plan scarce hinted at by their employers with a ready comprehension which did credit to their intelligence. If a stake which never existed was a necessary link in the chain of evidence, that stake would be created out of thin air; if a barren strip of porphyry or a body of paying ore was required, porphyry or ore would be discovered in quantities and position to suit the demand.

Generally no instruction was requisite. An important witness summoned from a neighboring State would agree to come if allowed several thousand dollars for his valuable time and incidental expenses, and once on the ground, after a brief survey of the points in dispute, he would proceed to earn his wages by swearing voluntarily and positively to what he conceived would best serve the interest of his employer—but if drilling was needed it was never lacking. There were instructors on the ground who could take a witness through a drift or cross-cut and make him see clearly a seam of ore or a mass of barren rock along the same wall under the eye-opening influences of liquor and a per diem allowance. Some witnesses would require more than others, but every man had his price, unless he valued himself too highly. If one side summoned a long array of witnesses to attest a fact, the other side met the challenge by ranging a still greater number in line against them. If twenty-eight witnesses testified in favor of the Union Company, for example, fifty-seven would and did appear for the Yellow Jacket Company, and the number of witnesses subpœnaed was largely in excess of those actually called to the stand.

The same corrupt influences were brought to bear more secretly and less frequently perhaps upon the juries impaneled. In a district where everybody speculated in mining claims it was practically impossible to obtain an unprejudiced jury, but the bias was intentionally increased in many instances by di-

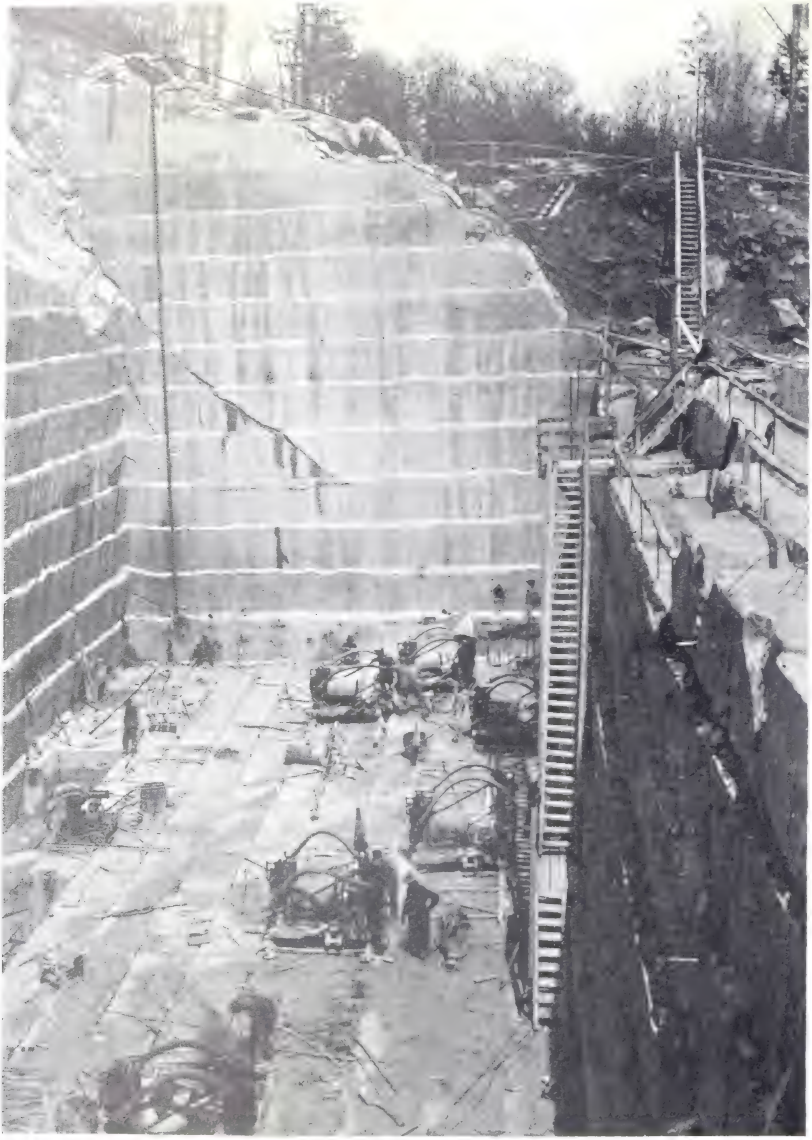
PLATE XLVI



U. S. Army Air Corps

COPPER MINE AT BINGHAM, UTAH

Mining is accomplished in the open air by tearing down the mountainside instead of burrowing into it.



Vermont Marble Company

A VERMONT MARBLE QUARRY

The "steps" are formed by sawing the marble into blocks and wedging them out. Vertical and horizontal cutters are at work on the bottom.

rect bribing. A discreet observer wrote with simple irony to the Virginia City Territorial Enterprise in 1865 (February 16th), to inquire "Whether the following transactions would disqualify a gentleman from serving as a juror in future: 1. Throwing out of the court-house window a paper on which was written 'See me with $1,000; I will then tell you to-morrow morning how the thing will go, and we can make money.' 2. Taking the wrapper from a cigar and having replaced it with a note on which my terms were written, leaving the inclosed cigar where my friend could get it. 3. Finding a note under the lining of my hat offering me '$5,000 provided you go for us,' but giving my verdict only to be fooled by the company." The inquirer fortified his assumed position by quoting from Johnson's Life of Addison the saying: "It is not necessary to refuse benefit from a bad man when the acceptance implies no approbation of the crime." The occurrences mentioned were notorious and illustrate the cruder Washoe methods of obtaining a favorable verdict. The public confidence in jurors as well as witnesses was sorely shaken. Even the integrity of the presiding judges did not escape suspicion. Disgraceful rumors were current assailing the honor of members of the highest territorial judiciary. The atmosphere of distrust was all-pervading.

Under these circumstances, therefore, it is not surprising that possession was accounted the surest confirmation of title and that the control of disputed claims was often determined by force. The Keystone Company drove away the miners of the Peerless Company, pitched their windlass and buckets down their shaft, and filled it up to the surface with rocks and earth. The workmen of the Grass Valley Company were suddenly assailed through a drift cut as a counter mine by the Bajazette and Golden Era Company, and forced to fly to the surface (August 11, 1863). The Uncle Sam Company "hustled the Centerville knights off their ground" (February 24, 1864) and filled up the hole they had dug. Yellow Jacket miners cut a drift into the Gentry Company's shaft (April 9, 1864), built a fire in it and smoked out the rival party. Resolved not to be ousted, the expelled miners rolled down rocks and dirt into their shaft until it was filled above the opening made by the hostile drift and began work a second time. The Yellow Jacket Company followed up their attack, opened the shaft again (April 22, 1864) and built another fire. Their rivals resolved to fight fire with fire, and threw down quantities of inflammable rubbish which soon sent up a dense black smoke. The Gentry shaft was closed at the surface and the smoke and vapors found their only vent through the Yellow Jacket drift, driving out the miners. The war was kept up for days "with all sorts of stinking smudges." An incautious Gentry miner was once nearly smothered, and the wind blew the strong odors to the neighboring houses with disgusting effect.

"Regular campaigns are carried on where two companies are working close to each other in disputed ground. Though neither company can see what the other is doing they can give shrewd guesses. With ear applied to the wall of his own drift the sagacious miner contrives to study out the whereabouts of his rival and the direction in which he is moving. Perhaps the miner finds that they are advancing in a line to intercept him. He then strains every nerve to get so far ahead that if they continue their course they must come into the drift behind him. To avoid this they give up the chase and turn on their proper course. Then the pursued become pursuers in turn, and start a drift to head off their enemies. Sooner or later the works cut into each other."[1] So the Baltic Company invaded the Caledonian lines, but were straightway smoked out by their rivals, April 26, 1864, and the Gould & Curry miners broke down the barricade erected by the Seneca men and cut their windlass and ropes to pieces.

Most of these conflicts were never brought to a successful conclusion. As a result the Comstock lode, with a total production of silver and gold to the value of more than $378,000,000, made few men rich. Moreover, enormous difficulties in mining helped to keep down the profit. Extraordinarily high temperatures were encountered, and great volumes of scalding water poured out of many fissures. But the miners thought that they were treading on the roof of a bank whose door they knew how to unlock. Lord (1883, p. 125-126) says:

---

[1] *Gold Hill News*, April 27, 1864.

> It is evident that economy was not a popular study with the managers of a prosperous mine on the Comstock lode in the early years of its development at least. This is in no way surprising. The mill haciendas were simply in keeping with the prodigal ideas of the time. Men walked the streets of Virginia City as if pacing the roof of a fathomless treasure house, and their heads were constantly in the clouds. They saw a network of silver beneath their feet and the fine strands widening into solid wedges of ore. The eyes of the soberest minded even were dazzled by the vision, and the fancy of the imaginative ran wild. No metaphor can exaggerate the prevailing delirium. It would appear that a silver mist enveloped the slopes of the Sun Peak and men moved and breathed in its unnatural atmosphere. Drunk with the vapor, all prudent considerations were laughed to scorn. Timid suggestions of the utility of thrift and the possibility of an approaching exhaustion of the ore deposits were unheeded or unheard. Every large stockholder in a productive mine counted himself a nabob and scattered his money broadcast like a prince bestowing largesses. The conception of the Brazilian spendthrift in Der Seekadet is scarcely a burlesque of the Washoe production. One fits his doors with handles of solid silver and buys a library like a ledge, by the foot; another fills his water-tank with champagne to enliven the guests at a wedding. Before the end of the year 1861 eighty-six companies, with an aggregate capital stock of $61,500,000, were organized to work the mines of the Comstock and outlying districts, and this number was largely increased in the years immediately following. Looking backward through an interval of twenty years men may wonder and smile at the delusion. It was different at the

time. In the unknown there is an almost infinite range of possibility, and who could then oppose the confident faith of the optimists except with unsupported doubts. The mines showed no signs of exhaustion, but on the contrary, every stroke of the pick revealed new treasures. Judged by the developments of the day, the mines bade fair to realize the sanguine anticipations of their owners. The nabobs in fancy might yet be nabobs in fact.

Property in Meteorites

Let us return now from the depths of the Earth to its surface. If a meteorite falls from the sky and embeds itself in your land, do you own it or does the finder? The decision upon the first case of this kind that was brought to the attention of the courts of the United States is interesting because it hinges upon scientific theories concerning the origin of the Earth. According to Shamel (1907, pp. 34-35):

> The ownership of meteorites, the bodies of mineral, usually metallic iron, which fall from the sky upon the surface of the earth, is one of special interest because it involves a direct legal construction of the theory of the constitution of the universe as expounded in the planetesimal hypothesis, the nebular hypothesis, etc. The first case of this kind of which there is a record in the United States is that of *Goddard* vs. *Winchell,* 86 Iowa, 71, 52 N. W., 1124, in which the dispute was to whether the owner of the land was also the owner of a meteorite which fell on his land, or whether it belonged to a third party who had seen it fall and dug it up and sold it to Winchell. This third party dug it up from a depth of three feet below the surface, where it had imbedded itself by the force of the fall. Goddard, the owner of the land, replevied it from Winchell, and the case went up to the Supreme Court of the State, which says in its decision of the case:
>
> "The subject of the dispute is an aerolite, of about 66 pounds' weight, that 'fell from the heavens' on the land of the plaintiff and was found three feet below the surface. It came

to its position in the earth through natural causes. It was one of nature's deposits, with nothing in its material composition to make it foreign or unnatural to the soil. It was not a movable thing 'on the earth.' It was in the earth, and in a very significant sense immovable; that is, it was only movable as parts of the earth are made movable by the hand of man. Except for the peculiar manner in which it came, its relation to the soil would be beyond dispute. It was in its substance, as we understand, a stone. It was not of a character to be thought of as 'unclaimed by any owner,' and, because unclaimed, 'supposed to be abandoned by the last proprietor,' as should be the case under the rule invoked by appellant. In fact, it has none of the characteristics of the property contemplated by such a rule.

"We may properly note some of the particular claims of the appellant. His argument deals with the rules of the common law for acquiring real property, as by escheat, occupancy, prescription, forfeiture, and alienation, which it is claimed were all the methods known, barring inheritance. We need not question the correctness of the statement, assuming that it has reference to original acquisition, as distinct from acquisitions to soil already owned, by accretion or natural causes. The general rules of law, by which the owners of riparian titles are made to lose or gain by the doctrine of accretions, are quite familiar. These rules are not, however, of exclusive application to such owners. Through the action of the elements wind and water, the soil of one man is taken and deposited in the field of another; and thus all over the country, we may say, changes are constantly going on. By these natural causes the owners of the soil are giving and taking as the wisdom of the controlling forces shall determine. By these operations one may be affected with a substantial gain, and another by a similar loss. These gains are of accretion, and the deposit becomes the property of the owner of the soil on which it is made.

"A scientist of note has said that from six to seven hundred of these stones fall to our earth annually. If they are, as indicated in argument, departures from other planets, and if among the planets of the solar system there is this interchange, bearing evidence of their material composition, upon what principle of reason or authority can we say that a deposit thus made shall not be of that class of property that it would be if originally of this planet and in the same situation? If these exchanges have been going on through the countless ages of our planetary system, who shall attempt to determine what part of the rocks and formations, of special value to the scientist, resting in and upon the earth are of meteoric acquisition, and a part of that class of property designated in argument as 'unowned things,' to be the property of the fortunate finder instead of the owner of the soil, if the rule contended for is to obtain? It is not easy to understand why stones or balls of metallic iron, deposited as this was, should be governed by a different rule than obtains from the deposits of boulders, stones, and drift upon our prairies by glacier action; and who would contend that these deposits from floating bodies of ice belong, not to the owner of the soil, but to the finder? Their origin or source may be less mysterious, but they, too, are 'telltale messengers' from far-off lands, and have value for historic and scientific investigation!"

The Investigation of a Claim

When a man becomes convinced that his land harbors a valuable mass of mineral matter, it is hard to shake his faith. One of the most distasteful tasks a geologist must perform in the pursuit of his investigation of a region is to assure a landowner that the prospect he was going to develop is worth more as grazing land than as mineral property. Sometimes work has actually started, there is no prospect of success, and the geologist must not hesitate to say so, and to give reasons why. D. W. Johnson investigated such a case, and in an unpublished manuscript gives the following account:

> I would like to present another case in which I was able, by observing the schistosity of the rocks, to disprove the sup-

posed existence of a large block of magnetic iron ore, and to prevent the waste of considerable capital in prospecting without the possibility of favorable returns. Narrow lenses of magnetite parallel to the foliation of the rock were known to exist in the upper part of a long, low ridge situated in the crystalline area of northeastern America. These lenses were too small and scattered to be valuable but they inspired the hope that important deposits might lie at greater depth. A foreigner who claimed to be an expert at locating magnetic iron ore by means of the magnetometer (an adaptation of the dip-needle well known to mining engineers) was engaged to make a magnetic survey of the region. He stated that a vast block of very pure magnetite unquestionably lay about 50 meters below the surface in the position shown in the diagram (Fig. 12). A development company was organized and oblique diamond drill holes were started at different points so as to cut the deposit and outline its exact position, its shape and its size—necessary preliminaries to mining. Not one of the seven drill holes indicated the existence of an ore body. Thereupon the engineer in charge of the drilling concluded that the foliation of the rock must have caused a progressive deviation of the drill holes so that they finally turned parallel to the foliation, as indicated by the broken lines (Fig. 12) and none of them penetrated the ore. Since such deviation of drill holes is a common phenomenon, and since the company was still under the magical influence of the foreign expert's magnetic survey, belief in the presence of the ore mass beneath the hills was not destroyed: it was somewhat shaken, however, and one of the individuals who had contributed considerable money towards the enterprise asked me to examine the locality and indicate the most logical method of continuing the search for ore. I studied the magnetic survey and found that the famous expert had determined the unknown deposit with such precision that he stated the exact per cent of iron and the tonnage present; my faith in his predictions was then greatly weakened, but my confidence received a ruder shock when I examined the actual conditions on the ground and noticed that no corrections had been made to allow for the irregular topography and the

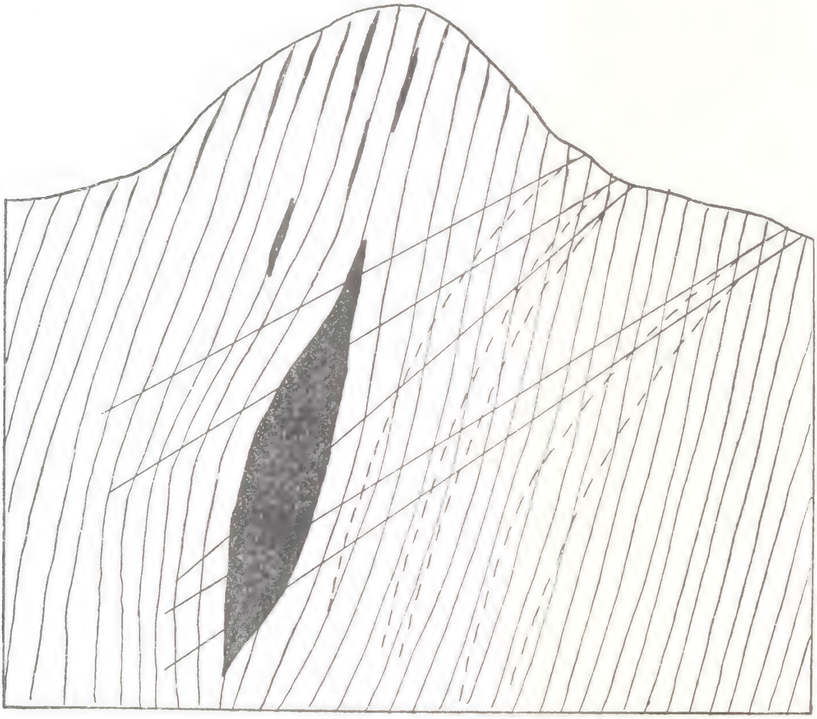


FIG. 12.—BLACK LENSE REPRESENTS SUPPOSED MASS OF MAGNETITE IN FOLIATED ROCKS. BROKEN CURVED LINES SHOW ALLEGED DEVIATION OF DRILL HOLES WITHOUT ENCOUNTERING MASS. SOLID OBLIQUE LINES SHOW TRUE COURSE OF DRILL HOLES, WHICH TRAVERSED THE POSITION OF THE SUPPOSED MASS WITHOUT DISCOVERING ANY ORE BODY.

superficial lenses of magnetite in the surrounding hills sufficient to cause a sensible deviation of the magnetic needle.

There was nothing left now but the problem raised by the diamond drilling and this was extremely simple. If, as had been stated, the drill holes had turned until they were parallel to the foliation, this foliation as preserved in the drill cores must change from oblique to the length of the cores near the surface and become parallel to the long axis of the cores in depth. The fragments from the upper parts of the holes must appear as in (a), those from the bottom as in (b) (Fig. 13). On the other hand, if all the cores from top to bottom resembled (a), it was proof positive that the holes had not deviated notably but had continued to cut across the foliation and had traversed the region supposedly occupied by the mythical block of ore. It was the work of less than half an hour to settle this question. I opened all the core boxes and found that not one of the seven cores showed any structure parallel to the cores. I was obliged to conclude that the region had been perfectly prospected by the drill holes, that the ore did not exist and that the proposed development would lead only to large and certain losses.

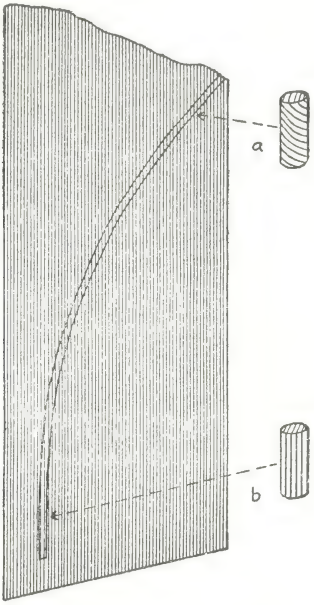


FIG. 13.—A DRILL CORE FROM A BORING TRANSVERSE TO THE FOLIATION WOULD APPEAR LIKE (A). IF THE BORING WERE DEFLECTED SO AS TO BECOME PARALLEL TO THE FOLIATION, THE CORES WOULD CHANGE TO THE TYPE (B).

Reservoir Sites

The large reservoirs that impound water for many communities are artificial lakes, and will not remain full if the sides or bottoms leak. It falls to the lot of the geologist to determine beforehand whether or not a certain valley will hold water. The responsibility is great, for his conclusions cannot be tested until after the dam is built and the water trapped.

The best way to illustrate the value of geology in such a connection is to mention a few cases in which the lack of easily acquired knowledge did not prevent the construction of dams that could not possibly be of any use. The first case (Bryan, 1929, p. 7) involves a reservoir that had every reason to be a success, for the water table lay near the surface and little water could leak out below. But when the water flooded the valley, it found an outlet through one of the valley sides in a manner that had not been foreseen.

> A masonry dam across Cedar River, a tributary of Snoqualmie River in Washington, was constructed with its south (left) end resting on "seamy" rock. The north (right) end rested in glacial material. Some leakage through the rock at the south end and around the north end of the dam took place, but large and disastrous leakage occurred through the glacial material that formed the ridge between the two rivers. When the water in the reservoir stood at an altitude of 1,555 feet, springs broke out in Snoqualmie Valley at an altitude of 990 feet. The hydrostatic head was 565 feet, and the distance 6,500 feet, making a gradient of 1 to 11. The emergence of this leakage in Snoqualmie Valley caused slumping of the hillside. The total loss of water was 30,000,000 gallons daily (46.5 second-feet), and since 1914 the reservoir has not been allowed to fill. . . . The glacial materials of the ridge were, however, obviously so coarse grained and porous that it was evident before construction to both geologists and engineers, . . that the ridge could not resist the movement of water from the reservoir on a gradient of 1 to 11.

Great difficulty is experienced in trying to build reservoirs if the water table lies far beneath the surface. A certain amount of leakage must be expected, but if the rocks are notably porous the project should be abandoned. Bryan (1929, p. 8) cites the following cases:

> The Jerome Reservoir, in Idaho, is situated in a depression underlain by several hundred feet of basalt flows. The water table is far below the surface, and leakage through the basalt, though the rock was protected by a cover of soil 10 feet thick in places, was so great as to cause the abandonment of the reservoir. The Hondo Reservoir, in southeastern New Mexico, is situated in a natural depression surrounded by fairly substantial limestone. Below a surface soil the floor is underlain by shale and gypsum, as shown by drill holes, and according to the best information the water table lies about 200 feet below it. After the reservoir was constructed leakage through the cavernous rock beneath it was so rapid as to cause the formation of sinkholes in the soil, and the loss of water was so great that the reservoir was abandoned.

Sometimes the leakage is confined to a small area and it may be stopped by a dike; but unless the conditions that brought it about are very local, such schemes are not feasible. It is much better to be reasonably sure that the reservoir will hold water before building the dam.

Tunneling Operations

The work of drilling a tunnel through solid rock brings an engineer into direct contact with geologic facts. He may be saved a great deal of money if he learns beforehand what he must cut through.

The following case is one of the many known to the late Professor James F. Kemp, which he was preparing to publish in a book illustrating the practical aspects of geology.[1] It emphasizes briefly the importance of obtaining geological advice in planning many bits of engineering work.

---

[1] Reproduced through the courtesy of Mrs. Kemp, though not in Professor Kemp's own words.

A certain railroad, while constructing its line through the folded mountains of Pennsylvania, found it necessary to tunnel through an anticlinal hill, and asked for estimates on the undertaking. A contracting company studied the ground, examined the outcrops on the top and on the slopes of the hill, and, since they were everywhere the same soft shale, submitted an estimate based upon a tunnel constructed wholly in that soft, easily quarried rock. Any geologist acquainted with the sequence and thickness of formations in that region would have warned the contractors that, below the thin covering of shales there lay a hard, resistant sandstone which composed the core of the mountain (Fig. 14). The contractors, however, made their offer and signed the contract without seeking such advice. The drilling began and the workmen were surprised when they came upon the massive sandstone, while the added expense entailed in penetrating such a rock ruined the contractors.

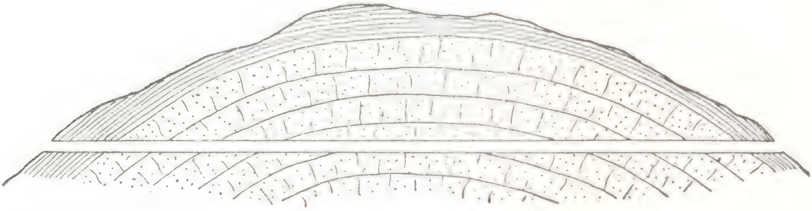


FIG. 14.—TUNNEL TRAVERSING ANTICLINAL ARCH OF HARD SANDSTONE COVERED BY SHALES.

The Geological Detective

The scientific detective is a popular figure in fiction. He obtains amazing results with a complicated lot of apparatus and keeps the cigar-chewing "man from headquarters" guessing until the end. Can the geologist ever qualify in this rôle? Not perfectly, perhaps, but his microscope can sometimes make it uncomfortable for the thief: at least if that culprit was so careless as to substitute a bit of stone for what he stole. C. P. Berkey has had many strange cases to solve, among them the following: In 1924 thirty-three cases of cheese arrived in Chicago from Italy, via New York. When they were opened by the customs officials five cases were found to contain large stones packed in straw and burlap bags. Where had the cheese been taken out? There were three places where the transfer was most likely to have taken place: namely, the point of departure, Italy; the point of transfer, New York; and finally, Chicago. But the stones themselves might tell a tale; so specimens were sent to Professor Berkey. He had thin sections made and then the microscope revealed material that could not be found in New York or Chicago or anywhere between, but that was common in southern Italy—a volcanic rock containing fragments of lava from Vesuvius.

The thief does not always play into the geologist's hands so well. A very similar case also referred to Professor Berkey involved a shipment of silk stockings from Milwaukee to Cape Town, South Africa, again via New York. This time paving blocks, gravel and bricks were found substituted weight for weight for stolen stockings. These are all common structural materials that are often transported long distances, and the case looked hopeless. However, some of the paving blocks were a granite that had certainly been quarried in New England. There were no records that this granite had ever been shipped for use in Milwaukee, but it was commonly used in New York. The specimens were wrapped in newspaper printed in New England; so there was a chance that both had been shipped in together, and New York was therefore the likely scene of the theft.

A Practical Use of Paleontology

Does paleontology have a practical application? It involves the study of creatures dead for many ages and seems remote from the life of to-day, but we do not have to look far for an answer to the question. The word *oil* brings to mind the paleontologist with his microscope correlating the strata from well to well and from region to region by means of the minute organisms that they contain. He is an almost indispensable part of the organization of a large oil company today. A similar use is made of fossils, large and small, to follow coal seams, building stone, beds of iron ore, and many other things. But can a fossil ever place a man in jail? Does it ever furnish just cause for withholding payment on a contract? New York State once called for estimates on the construction of a section of highway, stipulating that samples of the stone to be used be submitted with the estimates. A certain contracting company submitted a satisfactory estimate and produced specimens of a stone of high quality. The contract was signed and the road building began. When the work was finished, it did not give satisfaction and the state refused payment on the ground that the contractors had used a grade of stone inferior to that agreed upon. The contractors sued the state for their money; but, unluckily for them, the sample they had submitted with their original estimate contained a fossil that fixed its geologic age exactly. The state was able to prove that no rock of that age existed in any of the quarries from which the contractors had obtained the stone they finally used. One fossil cost the contractors dearly.

Physiography and the Law

Physiography is a relatively new branch of geology, which has wide application to the settlement of boundary disputes. Professor D. W. Johnson (1927, pp. 104-110), who has devoted much time to this phase of the subject, investigated and reported upon the interesting cases that follow:

> The chief portion of the City of New York is built on a long, narrow island, called Manhattan Island, bounded on the west by the Hudson River, and on the east by a branch of the sea known as East River. The property immediately bordering on the tide-water of East River is very valuable because factories or other industries located there have direct access to ocean transportation by vessels which may land at their very doors. You will readily appreciate, therefore, that in such a location a dispute over a few feet of ground may really involve many thousands of dollars, and hence be very bitterly contested by both parties.
>
> According to our law the land between high-water mark and low-water mark belongs to the people, through the agency of their government, unless it has been specifically alienated by grants to private parties sometime in the past. In the case before us this highly valuable strip of land *was* early granted

to private individuals, and my client had a clear title to everything between high-water mark and low-water mark in that part of New York City. As is customary in such cases, a line of pilings was driven along the low-water mark and the space inside the pilings artificially filled with all kinds of debris until the sea could no longer overflow the land, even at high water. Thus land which at first seemed of little use came to be classed among the very important lands in the city.

One result of the artificial filling was to bury and conceal the old high-water line. Instead of a natural beach slope on which the high-water line can be observed and measured, we have to-day, and have had for very many years, only a broad stretch of artificial ground, composed of ashes and other debris, with nothing whatever to show where the high-water line was located. Under these conditions dependence is usually placed on maps, property surveys, and other human records in order to determine where boundary-lines between properties should be located; and it might easily occur that where maps are contradictory a man would build over the old high-water line without realizing it.

Now it happens that in the region in question some maps show that the old high-water line followed the course A, B, D (Fig. 15), while other maps represent it as having the course A, C, D. My client, whom we will call Smith, owned the filled land from the line of pilings, at low-water, to the high-water line, that is to say, either to ABD or ACD; while his neighbor, Jones, owned the land above the old high-water line, that is to say inward from ABD or ACD, always depending of course upon which of these two lines really indicated the true position of high-water before the artificial filling concealed the natural conditions. I suppose it is hardly necessary for me to say that Smith insisted that the correct location of the high-water line was at C, while Jones claimed with equal vigor that it was at B. As the two men were not very friendly, and each had plenty of money, the contest dragged along in our courts for many years.

Jones, exercising the right he claimed to the disputed territory, erected a building, the corner of which extended over this territory. Smith brought suit to eject him from the premises and to recover damages. The whole case hinged on the determination of the true location of the high-water mark. If it was located at C, Smith owned the strip of land in dispute and Jones must remove his building. But if the high-water mark was located at B, Jones owned the disputed land and Smith's suit at law must fail. Each side produced an array of maps, surveyors, and other witnesses to show that the high-water line was located where favorable to its interests; but the burden of proof being on Smith, he was unable, in view of the contradictory nature of the evidence, to convince court

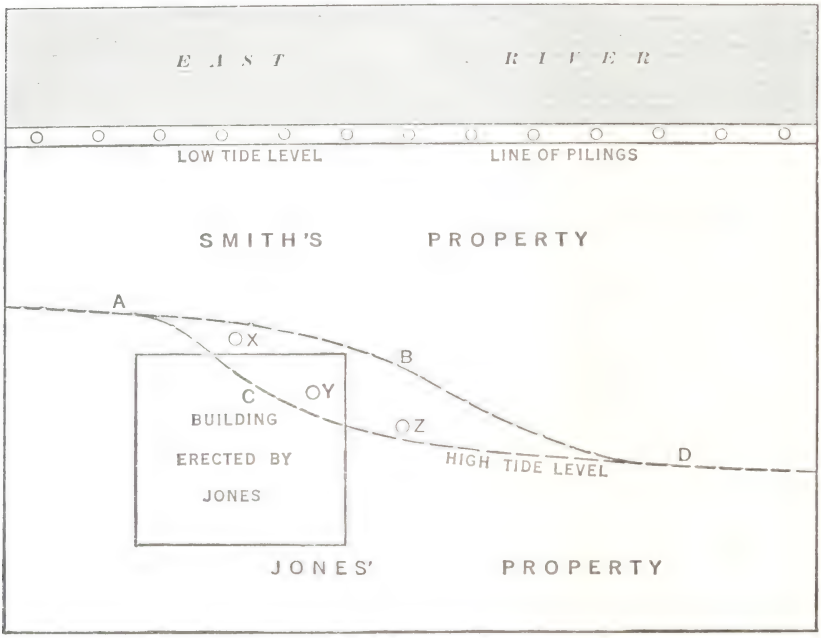


FIG. 15.—FEATURES INVOLVED IN THE NEW YORK HIGH-WATER LINE CONTROVERSY. THE DASHED LINES ABD AND ACD ENCLOSE THE PROPERTY UNDER DISPUTE. X, Y, Z ARE THE EXCAVATIONS MADE TO DETERMINE THE FORMER HIGH-WATER LEVEL.

or jury that Jones' building really trespassed on his property. New trials were granted on various grounds, such as the discovery of new map evidence, but in every case Smith lost.

In 1902, after the case had been before the courts for a number of years and Smith had been unsuccessful in his efforts to oust Jones, and while the case was again pending in the Appellate Division of the Supreme Court of New York, it occurred to Smith's lawyers . . . that there might be some scientific method of determining the former position of the high-water mark with an accuracy not shown by the old and contradictory maps. It was at this stage in the history of the case that I was called in by Smith's attorneys, and asked to determine, if possible, whether or not the building erected by Jones extended over the high-water mark as it existed in the earlier days of New York, before artificial filling concealed its true location. In other words, I was asked to determine whether the high-water formerly reached to C, or only to B. If I could do this, it would settle once for all a case which had been in the courts many years and had cost many thousands of dollars.

To solve the problem I sought and found three kinds of evidence, which demonstrated beyond any possibility of doubt that the former high tides reached to the line C, and hence that Jones' building *did* trespass upon the property belonging to my client Smith. The first line of evidence depended upon the fact that there are certain forms of life which depend for their existence upon the physical conditions occurring only at or near high-tide level. Thus the salt marsh grass, *Juncus gerardi,* grows from near high-tide level to a little above; another grass, *Spartina patens,* grows from just below to just above mean high water; while a third, *Spartina glabra,* does not quite reach to the high-water level. In a similar manner there are marine shells which require to be exposed to salt water and the free air alternately, different species demanding different exposures to each, so that some thrive only at high-water level, others a little lower, and so on. If I could find traces of high-tide vegetation or shells in their natural positions in the disputed territory, this would prove the justice of my client's claim to that valuable bit of land.

I first made an excavation at X, in the disputed strip, going down through the artificial filling of ashes and other debris until I encountered the natural soil below. This consisted of ordinary beach sand, with some large boulders beautifully rounded as by the wearing action of the waves charged with sand,—just such boulders as many of you have noticed along your own shores. The contrast of the natural sand and boulders with the artificial filling was clear and distinct, and left no doubt that we now had revealed at the bottom of the excavation the old shore as it existed prior to the filling. There was in this case no evidence of marsh deposits; but I gathered material for a microscopic examination to see if high-tide forms of animal life might possibly be preserved in it. Inasmuch as marine shells in the beach sand would prove nothing, since these might be washed up well above high-tide level by the dash of storm waves, it was necessary to find shells growing in their natural condition, attached to the rocks in positions which it would be impossible for them to occupy except when they were alive. Accordingly I scraped the overhanging lower sides of the large rounded boulders, in the hope that the adhering ashes of the fill might reveal shells which were growing in their natural state attached to the under sides of the boulders at the moment, many years ago, when the ashes were poured over them to bury them. In this I was not disappointed; for with the aid of the magnifying glass it was easy to pick out many crushed and some whole shells of two species, both of which were forms characteristic of the high-tide level of the shore. These shells, presented in court, furnished conclusive proof that the high tide formerly reached to the line C, and that Jones' building trespassed on my client's property.

To check the proof offered by the shells I had the City Surveyor of New York run a line of levels from a bench-mark showing mean high-tide level at another point on East River, to the old beach as exposed in the excavation; and this showed clearly that the surface of the old beach at this point was just a few inches below the high-tide level.

The third line of evidence was an ocular demonstration of the rising of the tide on the uncovered beach. The artificial fill was very porous, and readily admitted the sea water from East River to percolate through it at the time of high water. Examination proved the absence of land waters which might improperly affect the level of the water surface in the excavation, while a study of the tide tables showed the approximate relation of the tides of that day to mean high water. With these points checked, and the possibility of correcting abnormal variations of the tide by known bench marks, it was a simple matter to have witnesses actually observe the rising of the tide on the old beach within the disputed territory. A second excavation at Z reinforced the results of the first, and finally a third excavation in the cellar of the building erected by Jones, at the point marked Y, firmly established the evidence in the most critical part of the land in controversy. We actually saw the tide rise on the old beach under Jones' building.

You will observe that no one of these three lines of evidence depended upon either of the others for its strength. Each of the three was independent and conclusive of itself. Together they made an array of physical fact against which the testimony of old maps was worthless. When the case was tried Smith won without the least difficulty, Jones was compelled to right the wrongs of his trespass, and the final chapter was written in a long history of litigation.

Property Boundaries

The next case again involves the ownership of a strip of land below mean high-water level and it is of particular interest because it marks the beginning of a series of studies conducted by

Johnson (1927, pp. 113-115) that have gradually removed the evidence for a "fact" of the past generation of geologists:

> I will return to my subject by citing a case in which the question as to whether or not the Atlantic Coast of America is undergoing a slow but progressive subsidence became a matter of great financial importance. As many of you may know, a majority of American geologists have long held that the coast in question is sinking at the rate of one or two feet per century. There is much evidence which seems to point to this conclusion, such as the presence of stumps of upland trees now submerged below sea level, of trees standing in the margins of bays along the coast, and of trees killed by salt water bordering bays or salt marshes. Such apparent evidence of subsidence is so voluminous that I cannot repeat it at this time, although the critical analysis of it is in itself a most fascinating study. Suffice it to say here that the theory of subsidence became so firmly established in America and so widely accepted that even the newspapers made it a subject of comment. After Dr. Newberry, formerly professor of geology at Columbia University, had published an article supporting the theory of a gradual sinking of the land, one of the New York newspapers published a cartoon showing a broad waste of waters from which there projected only the summit of one of the Columbia University buildings. To the spire at the top of the building Dr. Newberry was represented as clinging with one hand, while in the other he waved a Columbia flag, as he shouted proudly across the waves, "I told you so! I told you so!"
>
> It might seem that so theoretical a matter as the supposed sinking of the coast of America could never become involved in practical legal proceedings in which lands worth millions of dollars were at issue. But in the Commonwealth of Massachusetts the East Boston Land Company, owner of valuable water-front property on the shores of Boston Harbor, made a claim not only to the land down to the level of high water,

but even to the land extending out under the sea some distance, on the ground that since their predecessors in title first acquired the property down to high-water mark, in the early colonial days, the gradual subsidence of the coast had carried the high-water mark below the sea a certain number of feet. On the basis of a subsidence of 1 or 2 feet per century, the high-water mark of the 17th century ought to be equivalent to the present submarine contour 3 to 6 feet below high-tide level. By driving pilings out in the water along this contour, and artificially building out the land to the pilings, the Company could convert a series of tidal mudflats into valuable wharf property, and deprive the people of Massachusetts of the usual strip between high-water line and low-water line, ordinarily belonging to them under our laws.

The court ruled that if the East Boston Land Company could demonstrate that there had been a regular and progressive subsidence at a known rate since their predecessors first acquired title to the lands down to high-water mark, then the Company might claim everything extending seaward to the appropriate submarine contour; but that if the rate of subsidence were irregular or unknown, so that it was not now possible to determine which submarine contour really represented the high-water line of two and a half or three centuries ago, then the disputed territory should belong to the Commonwealth of Massachusetts. Professor Crosby of the Massachusetts Institute of Technology was the expert retained by the East Boston Land Company, while I was one of the two retained by the Commonwealth to look after the interests of the people of the state. I then began the study of the problem of coastal subsidence which has interested me from that day to this. At the beginning I had no doubt as to the reality of the subsidence, for this theory was stated rather as a *fact* in the geological textbooks of that time, and I had learned it as an accepted principle of geology from my professors in the college and the university. The evidence seemed clear and conclusive that the land was sinking; and the only question in my mind was whether or not the *rate* of subsidence had been regular; and if regular, whether or not the precise rate was determinable.

You may imagine my surprise when I discovered that on critical examination one after another of the supposed evidences of recent subsidence proved to be fictitious. Not one of the apparent indications of land sinking would stand the test of rigorous scientific analysis. Every one of them could more logically be explained as the result of local tidal fluctuations or other causes not related to any recent change in the general level of land or sea. At the same time I discovered satisfactory proof that the coast had remained essentially stable for the last few thousand years. . . .

As a result of my investigations I was forced to conclude that the East Boston Land Company could not recover the disputed strip of land, not because the rate of subsidence was irregular or unknown, but because the very theory of subsidence on which their claim was fundamentally based was itself fallacious. The case never came to trial on this fundamental issue, possibly because their own expert advised them that it was impracticable to determine any definite and regular rate of subsidence.

Another case involving property ownership along a shoreline hinges upon a different point. A certain man and his predecessors in title had long owned a strip of beach called Fox Island Beach, lying between two headlands near Oyster Bay, Long Island. The town had levied taxes on the beach property for years, but some one finally discovered that when the land was first purchased from the Indians, two centuries and a half before, the deed included the salt meadow "to the beach" only. The town now claimed that the "beach" meant the whole sand barrier between the headlands and not the slope of sand upon which the waves play. The case turned upon interpretation of the original Indian deed and other purely legal matters.

The client first won, then lost, and while waiting for an appeal against the judgment to be heard, Professor Johnson was called upon to examine the beach. We will proceed in his words (Johnson, 1927, pp. 122-125):

> Let me now set before you the facts which I discovered. Most of them were readily apparent to any visitor to the locality, and their significance easily understood. In front of the two headlands, to which the beach was tied at each end, great boulders extended far out to sea; and the headlands themselves showed steep, wave-cut cliffs facing the sea, in the face of which other giant boulders could be seen embedded in the glacial debris. This association of features was clear proof to the physiographer that both of these headlands formerly continued seaward a great distance, and that the waves had cut them back, washing away the finer material to form beaches but leaving the great boulders as an evidence of the former extent of the land. As the beach in question is of the type which is dependent upon, and has its position determined by, the seaward ends of the headlands, I could not doubt that formerly the beach also was far out to sea in front of its present position. Thus we had physiographic proof that for a very long time the sea had been forcing the beach farther and farther back toward the south.
>
> An examination of records in the archives of the U. S. Coast and Geodetic Survey showed that nearly 100 years ago the Survey established bench-marks or signals on both of the headlands. By 1883 these had been undermined by the waves and washed away; and it was necessary to establish new signals farther back. By 1915 this second set of signals had been lost, and a third was erected still farther back. In 1922 I found that the waves had cut back one-third of the way to the new position. There was other conclusive evidence that during the last hundred years the headlands had continued to wear back with marked rapidity, carrying the beach back with them.
>
> The conclusive proof would be found by digging through the beach to see what was below; for if the beach had really

moved backward over the salt meadow, the meadow sod should be found buried under the beach. I made a large number of excavations through the beach and under all parts of it found the meadow sod. Specimens of the buried marsh deposits were shown to the court and jury at the trial, and an expert botanist and expert chemist who made similar excavations and examined the plant remains and analyzed the soils they found, corroborated this part of the evidence. The proof was absolute that the entire beach had moved southward over the marsh for an unknown distance.

There now remained only the question as to how far the beach had moved back in the last 250 years. From a study of this coast and the records of its changes and comparison with other similar coasts of known composition and exposure to marine attack, it was possible for me to say with reasonable certainty that the rate of movement had been not less than 2 feet per year, and possibly was as great as 4 feet per year. In other words, I could show that 250 years ago both the headlands and the beach were from 500 to 1,000 feet out to sea, north of their present positions; and where now is the beach was then all open salt marsh, extending northward to the rear of the beach as it then existed.

You see the consequence of this conclusion. The Town of Oyster Bay had admitted that the old Indian deed of 250 years ago gave all the salt marsh to my client. Now it was clear that the salt marsh thus conveyed at that time covered all the area in dispute, and that the original property lines of my client and his predecessors extended past the present beach and out to sea. The waves had in the course of centuries thrown the beach back upon my client's salt marsh; and, according to our law, when the waves, winds, or other forces of nature move a beach over upon another's property, the beach thenceforth belongs to that other. In this case it was thus clear that even if the beach was originally excluded from the Indian deed, the natural changes of the centuries had shifted it into territory which certainly belonged to my client.

The finding of the salt meadow sod under the beach placed our opponents upon the two horns of a very uncomfortable dilemma. We have a principle of law that where a sand-beach rests upon salt-meadow, title to the meadow gives title to the beach also, unless the latter is clearly and specifically excluded. Now, if our opponents claim that the geological evidence of beach retreat in 250 years is unreliable, and that the beach is really just where it was 250 years ago, they thereby confess that the beach must then have rested on the salt marsh when the Indian deed was made; and my client wins the property on the principle that title to the marsh carries with it title to the beach resting on it. Or if they claim that there was no meadow under the beach at that date, then they confess that the beach must have moved entirely away from its former position in order to get on the marsh; and my client wins the property on the principle that natural agencies shifted the whole beach into the territory admittedly owned by him.

The Red River Boundary Suit

The Red River follows a meandering, shifting course between Oklahoma and Texas. For long nobody cared to know exactly where the boundary between the two states lay, though as early as 1890 the vagueness of the term "following the course of the river," contained in the original treaty of 1819 between Spain and the United States, was called into question. In 1896 the Supreme Court interpreted this as making the south bank of the river the boundary line and there the question rested until oil was found in the river valley in 1919. Then the exact boundary became a matter of prime importance and scientists were called upon to study the river and so far as possible interpret its behavior during the last one hundred years.

The following quotations from E. H. Sellards (Sellards, Tharp, and Hill, 1923, pp. 16-21) repay study because they show how, under the existing law, the vagaries of a river may shift boundaries:

Throughout its course from the 100 meridian to the southeast corner of Oklahoma the Red River flows in a valley entrenched between more or less well defined bluffs. The width of the valley between the bordering bluffs varies from between one and two miles at and near the 100 meridian to several miles in places in the lower reaches of the river. The height of the bordering bluffs varies from as much as 100 feet or more to a very moderate height of a few feet followed by a gentle slope back to the higher land. The River Valley, as the term is here used, includes the land between the bordering bluffs consisting of the channel or channels to which the river is confined at low water stages; a sand stretch or sand flat varying from one mile or more in width in places in the upper part of the river to a narrow belt of sand or sand bars in the lower river; and valley lands varying in height above the average water level and normally covered by vegetation. The sand flat in the upper river and the sand bars in the lower river are overflowed at a moderate flood stage and are free of vegetation or nearly so.

Although by the decision of 1896, reaffirmed in 1921, the south bank of the river had been made under the treaty the boundary line between the two states, it remained to be determined what constituted the south bank of the river; where on that bank the boundary line should be drawn; and whether or not the boundary line had been affected by changes in the course of the river during the one hundred years since the treaty was made.

Much of the scientific testimony was concerned with the habits of the river, particularly in building its valley lands. With rivers in general the valley lands of course are built chiefly as the result of sediments deposited on or against the existing lands. Thus an existing valley if it is being added to at all is added to and enlarged gradually by the deposition of sediments. In legal terminology the gradual addition of new land to old by the deposition of sediment carried by the water of the river is known as accretion, and it is a long established rule in equity that when a river which forms a boundary, changes its course as a result of land added by accretion, the boundary line changes with the change in the river. Just where the channel of the Red River was located in the valley throughout the whole course of the river one hundred years ago, when the treaty was made with Spain, it is obviously impossible to determine. However, such changes as have been made by accretion are immaterial, since in any case the boundary would follow the river.

On the other hand it is an equally well established principle of law that where a river changes its course abruptly as in the case of an ox-bow cut off, the land between the new and the old channels remaining undisturbed, under these conditions the boundary does not follow the river in its new channel but is construed as following the channel abandoned by the river. If therefore the Red River in making whatever changes it may have made throughout its course in the past one hundred years since the treaty was made has changed by avulsion, then under these conditions the boundary line according to established legal precedent must follow the old channel of the river of the time when the treaty was made. For these reasons it became important to determine by what process the river has built additions to its valley land and in what way it has changed its channel.

Contentions of the United States and Oklahoma

In testimony submitted in connection with the boundary suit some of the scientists representing the United States and Oklahoma submitted the thesis that in the upper part of the Red River west of the west line of Clay County the valleys of the river are built up and added to by a process described as "island building," the new land being first formed in the bed of the river as an island and subsequently attached to the mainland. Under the terms of the treaty all the islands in the river were to be the property of the United States. Hence newly formed islands in the river would obviously be the property of the United States and presumably would continue to be the property of the United States after their union with the mainland.

If the "island theory" should be accepted there would still remain the difficult problem of determining how much land had been added in this way within the past one hundred years. However some of the scientists representing the United States and Oklahoma estimated that the destruction of the banks and building of new lands progressed at such a rate that all of the valleys in the upper course of the river with minor exceptions had been destroyed and remade within the past century.

The theories advanced, if sustained, would have resulted in placing the state boundary line at or near the foot of the Texas bluff, thus throwing practically all of the river valley land of the upper part of the river into the State of Oklahoma. That is, under this interpretation Texas constantly loses by erosion of the banks, but never gains by deposition of the eroded sediments, the rate of loss progressing with such rapidity that practically the whole of the valley land in the upper stretches of this river has been lost to Texas within an interval of one century.

The investigations centered on one particular part of the river, known as the "Big Bend" near Burkburnett in Wichita County, the land in this bend having become very valuable by reason of the discovery of oil underlying the river valley. The investigations, however, were by no means confined to this bend and it is in any case recognized by all parties that the principles, which apply to river action at this locality apply likewise to the upper stretches of the river. With respect to the "Big Bend" it was held by at least one scientist representing the United States and Oklahoma, Dr. H. C. Cowles, that at the time of the treaty with Spain one hundred years ago, the channel of the river in this bend flowed at the foot of the Texas bluff. Other scientists representing the United States and Oklahoma, including L. C. Glenn, Isaiah Bowman, and C. H. Miller, placed the river of one hundred years ago near, but not actually at the bluff. These claims with respect to the "Big Bend" were made notwithstanding the fact that at the present time the river valley at this locality is in excess of one mile in width at its widest part, the river now flowing at the foot of the Oklahoma bluff opposite the bend. Trees in this valley in excess of one hundred years of age were said by the ecologists representing the United States to have had their inception on islands. These contentions, if sustained, would have placed this, as well as other Texas valleys, in the State of Oklahoma.

Contentions of the State of Texas

The State of Texas, on the other hand, maintained that neither the Red River channel, nor the sand stretch which borders the channel, nor any part of the channel or sand stretch lay adjacent to the Texas Bluff in the Big Bend area so recently as within the past one hundred years. With regard to changes in the course of the river, it was contended that in this river, as in other rivers, the change throughout the entire course of the river occurs in some instances by erosion and accretion and in some instances by avulsion, and that normally in this river where the land is being built up, as has been done in the past ages in the Big Bend area, the change of the course of the river is by erosion and accretion. The larger valleys are regarded as in general exceeding one hundred years in age, at least in their older lands. Around the original nucleus of the valleys, in most instances, newer lands have been added from time to time, the controlling building process being by accretion. Ecologic studies indicate that the older portions of the Big Bend and other larger valleys have reached the climax stage of plant development, in this respect agreeing with the adjacent terraces and uplands. Under this interpretation the valley lands on the south side of the river belong wholly to the State of Texas throughout the entire course of the river where it forms the boundary.

The evidence presented in this suit may be classed as: (1)

Physiographic, including discussion of the physical features on the valleys, such as sand dunes, their age and habits of building and shifting, sand bars, back valley streams, marginal fans, old stream channels and interdune depressions: (2) geologic, including discussion of sedimentation of river valleys in general, and such evidence as was available from fossils, particularly the more or less well mineralized bones of the buffalo and other animals formerly living in the valleys; (3) agrogeologic, including thickness, method of accumulation, age indications, alteration and succession of soils; and (4) ecologic, including relation of the vegetation of the valleys to that of the upland, as well as the age indication of the timber, shrubs and herbaceous vegetation of the valleys.

The Decision of the Supreme Court

Under the decision rendered by the Supreme Court the river valley land up to the margin of the sand bed of the river remains in the State of Texas, while the sand bed of the river to the middle of the channel is adjudged to be the property of the United States. The "cut bank" along the southerly side of the sand bed constitutes the south bank of the river, and the boundary is on and along that bank.[1] The "Big Bend" is recognized as being larger now than sixty years ago, the enlargement being by accretion. On the outer part are physical evidence of the formation being comparatively young, and on the inner of being old. The boundary in the Big Bend as elsewhere on the river is placed at the cut bank, around the northerly limits of the valley.

---

[1] The term "cut bank" which appears in this decision is a term introduced and used in the testimony as a convenient term applied to the more or less pronounced bank or declivity which borders the sand flat of the river and as a rule limits growth of vegetation towards the river. In some places this bank or declivity is scarcely perceptible, elsewhere it rises abruptly to an elevation of from one or two to fifteen or twenty or twenty-five feet above the sand flat, the maximum elevation being usually occasioned in part or entirely by sand dunes. The "cut bank" of the testimony and of the decision is therefore the place at which the vegetation covered land of the valley gives place to the sand flat of the river.

Other Boundary Cases

An amusing situation arises when a river is able to determine whether or not a man and woman are legally married. If the reader has grasped the relation between the boundary law and the manner in which a river shifts its channel the following case (Johnson, b, p. 112) will be clear:

> Between South Dakota and Nebraska the Missouri River in part forms the boundary, and here also the boundary line shifts with the changing, meandering channel. It is reported that in the region enclosed by one of these meanders a wedding ceremony was about to be performed when someone brought the news that the river, then in flood, was flowing across the neck of the meander. Now if it should prove that this cross-current was the main one, the wedding party was no longer in South Dakota, but in Nebraska; and the minister licensed to perform the marriage rites in South Dakota, had no right whatever to perform them in Nebraska. If the marriage took place as planned, and the current across the neck of the meander became the main course of the river, the happy couple would unhappily not be legally wedded. To avoid any such sad ending to the joyous occasion the party got in a boat, crossed to the north bank of the cross-current, and there where they *certainly* were in South Dakota the marriage ceremony was enacted. Had this precaution not been taken, and had the river continued to flow in both the old and new channels, as it often does for a time, you can see that it might have been necessary to call in an expert physiographer to determine whether or not the unlucky couple had ever been legally wedded.

It is not often that a man can move from state to state and escape the sheriff merely by tying or untying the painter of a boat. There are places where it can be done and one man at least would have been lucky had he known it before he fell off a gangplank and into the clutches of the law. The following incident (Johnson, b, pp. 112-113) is hardly "physiographic" but it illustrates the relation of rivers and the boundary law once more:

In the case of my home State of West Virginia the boundary separating it from the State of Ohio follows the northern bank of the river, leaving the whole current in West Virginia. But for purposes of legal administration it has been held that a boat connected with the northern bank by a rope or by a landing plank, is in the State of Ohio. Thus with your boat in Ohio, you can get it into West Virginia without moving it, simply by cutting a rope or lifting the plank. A negro having committed a crime in West Virginia, attempted to flee to Ohio, closely pursued by the sheriff. Jumping in a small boat the criminal rowed eagerly for the Ohio shore. The sheriff seized another boat and followed close behind. Near the Ohio shore was a large steamboat connected with the land by a narrow gangplank, and therefore legally in the State of Ohio. The criminal rowed close to the steamer and jumped aboard, followed immediately by the pursuing sheriff. Now had the criminal realized that on the boat he was as truly in Ohio, and therefore as completely out of the jurisdiction of West Virginia and its officers as though he were in the centre of the state, all would have been well for him. But in his eagerness to get the solid soil of Ohio under his feet he ran around the boat, and out over the narrow gangplank, where he lost his balance and fell,—into the water, and hence into West Virginia. The sheriff jumped in after him and arrested him.

Geology in the World War

During the World War geology began to take its place beside the other sciences that contribute to man's efficiency as a fighter. It was then realized for the first time that the geologist can render essential service at the front and, though the few existing geological officers spent much time combating prejudice and standing helplessly aside while impossible projects were undertaken, great gains were made. A few examples (Brooks, 1920, pp. 87, 105) that show conditions easily remedied by a little geological knowledge, are given below:

During the great battle of Verdun a body of troops was ordered to intrench itself on the high plateau of the Côtes de Meuse. Even a casual examination of the geologic map would have shown that the plateau was underlain by hard limestone with less than a foot of soil. This material could not be excavated with the light tools furnished or even with proper equipment in the time available. As a consequence there was a large and needless loss of life.

In part of the Lorraine sector the front-line dugouts were located by the French without any consideration of the underground-water conditions. As a consequence a large part of the dugouts constructed at great labor were quickly rendered useless by filling with water. We did the same thing. I recall an attempt at dugout construction at a locality where the responsible officer had been warned that he could not excavate to the depth required to obtain shelter. The location was in an exposed position, and a number of lives were sacrificed before the project was abandoned because of water.

In the early part of the war, when transportation facilities were crowded to the limit, the British brought road metal from England in ignorance of the fact that a geologist was able to designate readily accessible sources in the theater of operations. A responsible officer in our own service made a requisition for filter sand to be transported across the Atlantic, though the geologists of the American Expeditionary Force had already found localities where such sand could be procured in France.

During 1915 the German troops in the St. Mihiel sector were giving official recognition to the use of the witch-hazel stick in locating sources of underground water. The first duty of the geologist detailed to this sector was to collect data on the results achieved by this implement, so as to shake the confidence of the authorities in its efficacy. In our Army many large plants, such as hospitals and flying fields, were located without any definite knowledge of the source of needed water. In the

British Army, after the first year, no well drilling was permitted without the approval of the geologist in charge of water-resource investigations. There was no such rule in the American Expeditionary Force, and many wells were drilled with no adequate knowledge of the underground-water conditions. In many instances it was not until hospitals or other large plants actually had a shortage of water that the geologist was called into consultation.

Mining

Military mining during the late war was done on a scale which completely dwarfed all previous operations of this kind. In no field did the military geologist perform a greater service than in determining the physical conditions that affect underground warfare. A large measure of the success of the British mining is due to the detailed geologic work of Col. T. Edgeworth David

Though the French have long been the acknowledged leaders in military science, they appear to have failed to realize fully the application of geology to military mining. Many of the French officers were trained in geology, but some of their mining operations were more or less hampered through failure to make full use of the science by the employment of professional geologists. In spite of this handicap, some of the most brilliant mine attacks of the war were made by the French, and French methods and equipment were used by all the belligerents.

Mining is more or less controlled by all factors that affect military operations, such as relative strength and morale of the opposing forces, distance of objective, means of transportation, and availability of material. In mining, however, the underground conditions are of first importance and in the interest of success must be determined before any project is undertaken. In many positions the geologic conditions, such as ground water, tough bedrock, or broken or loose strata, may be such as to make military mining impracticable. Mining is feasible only when an army is in close contact with the enemy and must therefore be carried on under the most adverse conditions, such as shell fire, infantry attack, and difficulties of transportation. As a general rule all matériel such as mine timbers and machinery must be transported to the scene of operations on men's backs, so that usually only the simplest form of mechanical equipment for pumping, ventilating, and excavating is available. Adverse physical conditions that would prove little or no obstacle to mining in civil practice may therefore be absolutely prohibitive in war.

Relation of Geological Structure to Trench and Dugout Locations

The flooded trenches and uninhabitable dugouts in which men froze and soaked by turns on the battle lines of France and Russia were not all unavoidable. Sometimes a little knowledge of the fundamental principles of ground-water movement would have lessened the suffering of the essential hell in which the men lived. D. W. Johnson (1921, pp. 117-119) studied the conditions in many of these battlefields and the text and figure that follow show what might have been done:

> One effect of the increasing power of heavy artillery fire is to compel opposing armies to dig ever more deeply into the earth in search of protection. Shallow trenches are deepened, and dugouts near the surface give place to elaborate underground chambers reached by long descending flights of stairs. Extensive galleries and tunnels are run for the purpose of sheltering large bodies of troops assembling for an attack, or to place and explode mines under the enemy's trenches. It is evident that the geological formation of some battlefields, consisting of well-drained pervious rocks, may be highly favorable to such military engineering works; whereas in other battlefields, underlain by strata saturated with water which cannot drain off, the construction of tunnels and dugouts and even the digging of deep trenches may be practically impossible. The Somme battlefield falls neither in the one class nor the other, for we have already seen that it is composed of both pervious

and impervious formations in alternating layers. Trenches, dugouts, and tunnels will be dry and habitable if excavated in the right formation; but if ignorance of the geological structure of the battlefield leads to excavations in the wrong formations, an army may find the waters beneath the earth more dangerous than the fire above. In a series of defensive works located on a hill slope in the Somme region (Fig. 16), a trench (No. 1) which is dug wholly in the relatively impervious loam will accumulate water, especially if the loam is of considerable thickness above the loess. But a trench (No. 2) located in such manner as to cut through into the underlying loess, or one (No. 4) located wholly in that pervious bed, will be dry, since water entering such trenches will drain off into the pervious formation. Trenches (Nos. 3 and 5) whose bottoms reach through the loess into the impervious clay-and-flint layer, or which are cut wholly in that layer, will hold water so effectually as to make their occupation extremely trying to the men; but if a trench (No. 6) in the clay cuts through into the pervious chalk the water will quickly drain away. Trenches cut only in the chalk (No. 8) will likewise be dry.

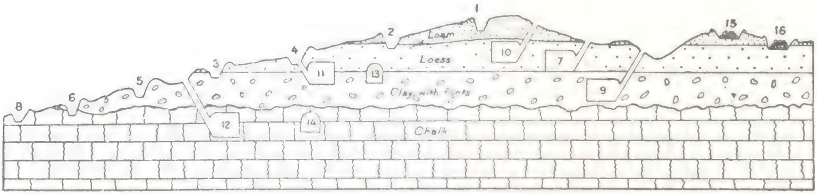


FIG. 16.—GEOLOGIC CROSS-SECTION OF A TYPICAL HILL IN THE SOMME BATTLEFIELD, SHOWING POOR LOCATIONS (ODD NUMBERS), AND GOOD LOCATIONS (EVEN NUMBERS) FOR TRENCHES, DUGOUTS, AND TUNNELS, AND MUNITION BUNKERS. REPRODUCED FROM DOUGLAS JOHNSON: "BATTLEFIELDS OF THE WORLD WAR," AMERICAN GEOGRAPHICAL SOCIETY'S RESEARCH SERIES, NO. 3, NEW YORK, 1921.

A dugout (No. 7) excavated wholly in the loess but with its bottom close to the contact of the underlying clay will be very wet, because the flow of underground water is at a maximum through the pervious beds just over the surface of the impervious formations; while a dugout (No. 9) wholly in the clay will also be wet, since, although the water drains in more slowly through the dense clay, it has no chance to escape. Dugouts (Nos. 10 and 12) wholly in the loess and chalk, and not close to contacts with underlying impervious beds, will be comparatively warm and dry. Dugout No. 11 is in a particular bad location, since waters flowing through the loess just over the clay contact will pour into the excavation from the upper walls and will be effectually impounded in the clay basin formed by the bottom of the excavation. Of the two tunnels No. 13 will give endless trouble for the same reason, whereas No. 14 will be dry. Even munitions bunkers may be located wrongly, as when they form basins in the impervious loam (No. 15) and hold the water from every rainfall; or correctly located (No. 16) so as to permit rainfall to drain off through the pervious loess.

The hazards of war do not always permit an army to select the terrain on which it will fight. Nevertheless it is evident that in a region like the Somme the terrain on which battle is delivered may be intelligently or unintelligently utilized. Unfortunately it happened during the great war that a higher officer, even a general of engineers, would sometimes remain blindly unaware of the vital relation of geological structure to the fighting power of his army, while his subordinates complained bitterly of the wasted effort and the unnecessary suffering which such ignorance entailed. Dugouts were excavated and then found useless because it was impossible to drain them. Tunnels and mines driven at great cost of time and labor were abandoned before attaining their object, because a water-bearing zone above or below was cut into and the workmen "drowned out." Men suffered misery in trenches deep with mud and water. And all this when changes of but a few feet in surface location or differences of a few feet in depth of excavation, perfectly feasible from the tactical point of view, would have avoided the damage incurred. Even with no change of location, drainage could often be effected by sinking in the bottom of the wet trench or dugout a narrow subsidiary trench reaching into an underlying pervious formation, or by driving pits or wells down into that formation so as to let accumulated waters escape below. With the lapse of time and at the cost of bitter experience these facts became more and more widely known.

BIBLIOGRAPHY

Chapter XIII—Geology in Modern Life

A. H. Brooks, *The Use of Geology on the Western Front.* U. S. Geological Survey, Professional Paper 128-D, 1920, pp. 87, 105.

Kirk Bryan, *Geology of Reservoir and Dam Sites with a Report on the Owyhee Irrigation Project, Oregon.* U. S. Geological Survey, Water-Supply Paper 597-A, 1929, pp. 7, 8.

Douglas W. Johnson,
Battlefields of the World War. American Geographical Society, Research Series No. 3, 1921, pp. 117-119.
Paysages et Problèmes Géographiques de la Terre Américaine. Paris: Payot, 1927, pp. 104-110, 112-115, 122-125. (Extracts are from author's MS. translation.)

Eliot Lord, *Comstock Mining and Miners.* U. S. Geological Survey, Monograph 4, 1883, pp. 10-14, 37-40, 125-126, 134-137.

E. H. Sellards, B. C. Tharp, and R. T. Hill, *Investigation on the Red River Made in Connection with the Oklahoma-Texas Boundary Suit.* University of Texas Bulletin 2327, 1923, pp. 16-21.

Charles H. Shamel, *Mining, Mineral and Geological Law.* New York: Hill Publishing Company, 1907, pp. 34-35, 91-92, 99, 233-236.

Additional material is taken from unpublished matter credited to the proper author in each case.

CHAPTER XIV

THE SCOPE AND METHOD OF GEOLOGY

Universality of the Geologic Processes

EVERY age has had its scientific leaders. In every age it has been the endeavor of these leaders to know the phenomena of Nature and to understand their causes and their interrelations. The naturalists of Classical times were the Greek philosophers. Through their own efforts, they came to understand a surprising number of the phenomena that puzzled many who came afterward. In the scientific obscurity of the Middle Ages, much of the knowledge of these wise men was lost, and many of the Earth processes with which we are familiar to-day have been thought through at least twice, by very different people and at very different times.

Looked at in the large, the first step in that rationalization of knowledge of the Earth, which we call the Science of Geology, was the clear perception that all parts of the Earth's surface are operated upon by the same general forces, and that it is merely by different combinations of these forces that diverse landscapes are moulded.

Just when this knowledge became general is uncertain, but that the facts were early realized is evident in this quotation from John Woodward (1695):

> And wheresoever I had notice of any considerable *natural Spelunca* or *Grotto:* any sinking of *Wells:* or digging for *Earths, Clays, Marle, Sand, Gravel, Chalk, Cole, Stone, Marble, Ores* of Metalls, or the like, I forthwith had recourse thereunto; where taking a just account of every observable *Circumstance* of the Earth, Stone, Metall, or other Matter, from the *Surface* quite down to the *bottom* of the *Pit,* I entered it carefully into a *Journal,* which I carry'd along with me for that purpose. . . . I likewise drew up a *List of Quœries* upon this Subject; which I dispatch'd into all Parts of the

World, far and near, wherever either I myself, or any of my Acquaintance, had any Friend resident to transmit those *Quæries* unto. The Result of this was that in time I was abundantly assured that the *Circumstances* of *these Things* in *remoter Countries* were much the *same* with those of ours *here:* that the *Stone,* and other *terrestrial Matter,* in *France, Flanders, Holland, Spain, Italy, Germany, Denmark, Norway,* and *Sweden,* was distinguished into *Strata,* or *Layers,* as it is in England: that those *Strata* were divided by *parallel Fissures:* that there were enclosed in the *Stone,* and all the other denser kinds of *terrestrial Matter,* great numbers of *Shells,* and other Productions of the *Sea;* in the same manner as in *that* of *this Island.* To be short, by the same means I got sufficient intelligence that *these Things* were found in like manner in *Barbary,* in *Egypt,* in *Guiney,* and other parts of *Africa:* in *Arabia, Syria, Persia, Malabar, China,* and other *Asiatick* Provinces: in *Jamaica, Barbadoes, Virginia, New-England, Brasil, Peru,* and other parts of *America.*

The Doctrine of Uniformitarianism

After the simplicity and unity of the Earth forces was perceived, the next step was the realization that the same forces were operating in antiquity that are operating now; that the processes of gradation are essentially uniform not only in place but in time as well. To James Hutton of Scotland belongs the honor of this discovery. But the deep-rooted prejudices and erroneous beliefs of others less clear-sighted had to be overcome. The patient efforts of Hutton, his exponent John Playfair, and a generation of their followers were required to establish permanently the new "doctrine of uniformitarianism". This doctrine established the fact that processes now operating on the Earth, if given sufficient time, are competent to effect the profound changes to which the geologic record bears witness. "The present," said Hutton, "is the key to the past".

In order to appreciate the revolutionary character of this doctrine, it is necessary to realize that for a long time it had been firmly believed that all of the Earth's history embraced but a few thousand years, and that the great changes known to have occurred in the Earth's crust as well as in the organic world came about abruptly, through a series of mighty cataclysms.

Amos Eaton was a "catastrophist." In his *Conjectures Respecting the Formation of the Earth* (1818) he voiced his belief that the rocks had settled out of a universal ocean, and that internal heat had then caused them to be tilted, their projecting ends forming the first islands and continents. He continued (Merrill, 1904, p. 238):

> These, however, were not the continents of the present day, which were conceived then to be at the bottom of the primeval ocean, but were rather the continents occupied by antediluvians, and which are now in their turn probably at the bottom of the Indian Ocean. This land, he argued—
>
> "May have been supported by the meeting place of two vast segments of uplifted granite which contained beneath them an immense subterranean sea. Our present continents may now be supported in the same way and the meeting of the edges of segments form the granitic ridge which extends from Georgia to the Frigid Zone—that is to say, that which forms the Appalachian Mountain System.
>
> "In whatever manner the ancient world was supported, it is evident that when the wickedness of man drew down the vengeance of the Almighty, its foundations gave way and it sank to the bottom of the ocean never to be again uplifted."
>
> Incidental to this catastrophe, he conceived that there may have been a "vacuum wherein much water might subside"; or possibly several continents falling in contemporaneously, basins were formed—
>
> "sufficient to hold all the waters which had hitherto covered the continents of our day; or, perhaps, the pressure at the outer margins of the falling continents might force up the granite, which raised our continents out of the ocean. . . . At any rate, the fountains of the deep were broken up, and our continents, then at the bottom of the great deep emerged into open day. While this tremendous crash of Nature was going on, scales of

various thicknesses from the various strata were shot up, detached and broken, which gave formation to our surrounding hills, the ragged cliffs of the Catskill and the bleak brow of the Andes. Some were formed at the bottom of the sea by volcanic fires; others have arisen from various causes since the great deep retired."

Consider also the near-sighted argument (Verifier, 1878, pp. 72-74) of this "catastrophist":

. . . Why should the Avon on quitting Bristol have altered its course, and instead of running straight forward over the low ridge at Bedminster into the Bristol Channel, have turned north to encounter hills five times higher (400-500 feet), those of Leigh Downs, unless it had found the gorge of Clifton opened ready for it? That that gorge was produced by a great convulsion is undeniable from the remarkable fault a little below the Suspension Bridge, by which the strata on one side have suffered a vertical displacement of 800 feet above those on the other.

In both these instances we may fairly ask the erosionists what could possibly have induced *rivers to run up hill* to surmount ridges many hundred feet high, and then to saw through mountains many miles thick when a clear low gap was offered to them with the least possible amount of erosion?

Modern geology assures us that the original elevations of earth's surface determined the flow of the waters, and that their currents carved out the river valleys. How does this agree with the physical geography of our own country? In the Isle of Wight a high ridge of chalk running from E. to W. forms the back-bone of the island and the natural watershed, but the three chief rivers, the Brading brook, the Medina, and Yare, rise to the S. of the ridge and run N. into the sea, *through* this opposing ridge, by depressions evidently not made by water running from the watershed, which, as it is, yields only small rivulets. The same thing occurs in the drainage of S. E. England. The natural watershed of the oölite and chalk ranges is utterly disregarded by the Nene, Ouse, and Welland, all of which rise to the west of these hills, and by means of fractures across them enter the Wash, and through it the North Sea.

And again the same writer (Verifier, 1878, pp. 121-125):

. . . Those who believe in modern causes must accept as the certain result of their action that we owe to earthquakes in a great degree the perpetuation, nay the very existence of the habitable earth. They must acquiesce in a redistribution of land and water, as it is called, as now going forward—that is to say, the sea is to replace the land, the land the sea; they must admit that the land is gradually but certainly being washed into the ocean; that denudation, undoing at one moment what it has done at another, may be destined to work away, "in the long ages of the future, until it has worn down the solid land, and mountains and glens have alike disappeared."

A philosopher, no less eminent than Playfair, even calculated the time it will take to transfer the whole of the dry land into the bosom of the ocean; and though he did not arrive at "safe conclusions," bolder men have been found of late, who, with "more exactness," assert that the whole globe is worn down 1 foot in 6,000 years; and, consequently, it will not take more than 4½ million of years to sweep away the whole American continent, and in 6 millions the entire rock-surface of the earth may be planed off in the same fashion.—See Lyell's *Elements*, pp. 1-92.

The result, then, of the most approved geological philosophy is to reduce the great globe, and all that it inherit, to a DEAD LEVEL!! unless by the antagonistic aid of igneous causes the unevenness of earth's surface can be restored—truly a difficult task, considering that while atmospheric effects operate over the whole globe, volcanoes are limited to about ⅟₅₀₀ part of it!!

The modern Huttonians lay it down as profoundly unphilosophical that the energies of nature should be supposed to have been greater at the creation of the globe than at present. Is there then any inconsistency in supposing that when a potter moulds a vase out of a lump of clay he should put forth his greatest energy and exert his utmost skill to finish it and turn it out perfect? That achieved, would there be any reason for his continuing to revolve his wheel slowly for an indefinite time? That the work of the creation of the earth was one of perfection defies all disproof. What need then to imagine that it was done by little and little; least of all can we admit a solution of the problem of cosmogony involving the absurdity that the work was left unfinished, and needs constant alteration by means of certain mechanical self-acting operations. The theory of natural development in other branches of natural history, whether true or false, at least infers improvement of structure and conformation. Applied to geology, it ends in deterioration, monotony, and stagnation. According to it the earth is to be planed smooth and bare, deprived of all that makes it beautiful, useful and habitable; converted into one monotonous plain, barely capable of keeping its head above water, save by the aid of occasional earthquakes!!

"The hunger of the mind to see every natural occurrence resting upon a cause," and the vanity of believing (spite of man's finite capacity) that modern science can account for and explain everything, appear to lie at the bottom of the confidence reposed in the Theory of MODERN CAUSES. Yet there is to hope that the more geology is studied in an earnest spirit, free from the mirage of attractive but shadowy hypotheses, the more it will be acknowledged that not blind force, however gentle, nor mechanical impulses, however gradual, rendered our planet what we find it. It will eventually be acknowledged that at the time and in the process of fashioning the globe, a power was exerted totally different from the present course of nature; that, in fact, it is not inconsistent with logical conclusions to hold that *an act of crea-*

tion may differ essentially from one of maintenance and conservation.

Compare the arguments above with the calm unassailable logic of Sir Charles Lyell (1860, pp. 1-3, 61-72, 195-196) probably the ablest proponent of the doctrine in the days before it became common knowledge. Lucidity and a scholarly quality characterize all of Lyell's writing:

> By these researches into the state of the earth and its inhabitants at former periods, we acquire a more perfect knowledge of its present condition, and more comprehensive views concerning the laws now governing its animate and inanimate productions. When we study history we obtain a more profound insight into human nature, by instituting a comparison between the present and former states of society. We trace the long series of events which have gradually led to the actual posture of affairs; and by connecting effects with their causes, we are enabled to classify and retain in the memory a multitude of complicated relations—the various peculiarities of national character, the different degrees of moral and intellectual refinement, and numerous other circumstances, which, without historical associations, would be uninteresting or imperfectly understood. As the present condition of nations is the result of many antecedent changes, some extremely remote, and others recent, some gradual, others sudden and violent; so the state of the natural world is the result of a long succession of events; and if we would enlarge our experience of the present economy of nature, we must investigate the effects of her operations in former epochs.
>
> We often discover with surprise, on looking back into the chronicles of nations, how the fortune of some battle has influenced the fate of millions of our contemporaries, when it has long been forgotten by the mass of the population. With this remote event we may find inseparably connected the geographical boundaries of a great state, the language now spoken

by the inhabitants, their peculiar manners, laws, and religious opinions. But far more astonishing and unexpected are the connections brought to light, when we carry back our researches into the history of nature. The form of a coast, the configuration of the interior of a country, the existence and extent of lakes, valleys, and mountains, can often be traced to the former prevalence of earthquakes and volcanoes in regions which have long been undisturbed. To these remote convulsions the present fertility of some districts, the sterile character of others, the elevation of land above the sea, the climate, and various peculiarities, may be distinctly referred. On the other hand, many distinguishing features of the surface may often be ascribed to the operation, at a remote era, of slow and tranquil causes—to the gradual deposition of sediment in a lake or in the ocean, or to the prolific increase of testacea and corals. . . .

The analogy, however, of the monuments consulted in geology, and those available in history, extends no farther than to one class of historical monuments—those which may be said to be undesignedly commemorative of former events. The canoes, for example, and stone hatchets found in our peat bogs, afford an insight into the rude arts and manners of the earliest inhabitants of our island (Great Britain); the buried coin fixes the date of the reign of some Roman emperor; the ancient encampment indicates the districts once occupied by invading armies, and the former method of constructing military defences; the Egyptian mummies throw light on the art of embalming, the rites of sepulture, or the average stature of the human race in ancient Egypt. This class of memorials yields to no other in authenticity, but it constitutes a small part only of the resources on which the historian relies, whereas in geology it forms the only kind of evidence which is at our command. For this reason we must not expect to obtain a full and connected account of any series of events beyond the reach of history. But the testimony of geological monuments, if frequently imperfect, possesses at least the advantage of being free from all intentional misrepresentation. We may be deceived in the inferences which we draw, in the same manner as we often mistake the nature and import of phenomena observed in the daily course of nature; but our liability to err is confined to the interpretation, and, if this be correct, our information is certain.

Prejudices Which Have Retarded the Progress of Geology

If we reflect on the history of the progress of geology, we perceive that there have been great fluctuations of opinion respecting the nature of the causes to which all former changes of the earth's surface are referable. The first observers conceived the monuments which the geologist endeavors to decipher to relate to an original state of the earth, or to a period when there were causes in activity, distinct, in kind and degree, from those now constituting the economy of nature. These views were gradually modified, and some of them entirely abandoned, in proportion as observations were multiplied, and the signs of former mutations more skilfully interpreted. Many appearances, which had for a long time been regarded as indicating mysterious and extraordinary agency, were finally recognized as the necessary result of the laws now governing the material world; and the discovery of this unlooked-for conformity has at length induced some philosophers to infer, that, during the ages contemplated in geology, there has never been any interruption to the agency of the same uniform laws of change. The same assemblage of general causes, they conceive, may have been sufficient to produce, by their various combinations, the endless diversity of effects, of which the shell of the earth has preserved the memorials; and, consistently with these principles, the recurrence of analogous changes is expected by them in time to come.

Whether we coincide or not in this doctrine, we must admit that the gradual progress of opinion concerning the succession of phenomena in very remote eras, resembles, in a singular manner, that which has accompanied the growing intelligence of every people, in regard to the economy of nature in their own times. In an early state of advancement, when a great number of natural appearances are unintelligible, an eclipse, an earthquake, a flood, or the approach of a comet, with many other occurrences afterwards found to belong to the regular course of events, are regarded as prodigies. The same delusion prevails as to moral phenomena, and many of these are ascribed to the intervention of demons, ghosts, witches, and other immaterial and supernatural agents. By degrees, many of the enigmas of the moral and physical world are explained, and, instead of being due to extrinsic and irregular causes, they are found to depend on fixed and invariable laws. The philosopher at last becomes convinced of the undeviating uniformity of secondary causes; and, guided by his faith in this principle, he determines the probability of accounts transmitted to him of former occurrences, and often rejects the fabulous tales of former times, on the ground of their being irreconcilable with the experience of more enlightened ages.

Prepossessions in Regard to the Duration of Past Time.— As a belief in the want of conformity in the causes by which the earth's crust has been modified in ancient and modern periods was, for a long time, universally prevalent, and that, too, amongst men who were convinced that the order of nature had been uniform for the last several thousand years, every circumstance which could have influenced their minds and given an undue bias to their opinions deserves particular attention. Now the reader may easily satisfy himself, that, however undeviating the course of nature may have been from the earliest epochs, it was impossible for the first cultivators of geology to come to such a conclusion, so long as they were under a delusion as to the age of the world, and the date of the first creation of animate beings. However fantastical some theories of the sixteenth century may now appear to us,— however unworthy of men of great talent and sound judgment, —we may rest assured that, if the same misconception now prevailed in regard to the memorials of human transactions, it would give rise to a similar train of absurdities. Let us imagine, for example, that Champollion, and the French and Tuscan literati lately engaged in exploring the antiquities of Egypt, had visited that country with a firm belief that the banks of the Nile were never peopled by the human race before the beginning of the nineteenth century, and that their faith in this dogma was as difficult to shake as the opinion of our ancestors that the earth was never the abode of living beings until the creation of the present continents, and of the species now existing,—it is easy to perceive what extravagant systems they would frame, while under the influence of this delusion, to account for the monuments discovered in Egypt. The sight of the pyramids, obelisks, colossal statues, and ruined temples, would fill them with such astonishment, that for a time they would be as men spell-bound—wholly incapable of reasoning with sobriety. They might incline at first to refer the construction of such stupendous works to some superhuman powers of a primeval world. A system might be invented resembling that so gravely advanced by Manetho, who relates that a dynasty of gods originally ruled in Egypt, of whom Vulcan, the first monarch, reigned nine thousand years; after whom came Hercules and other demigods, who were at last succeeded by human kings.

When some fanciful speculations of this kind had amused their imaginations for a time, some vast repository of mummies would be discovered, and would immediately undeceive those antiquaries who enjoyed an opportunity of personally examining them; but the prejudices of others at a distance, who were not eye-witnesses of the whole phenomena, would not be so easily overcome. The concurrent report of many travellers would, indeed, render it necessary for them to accommodate ancient theories to some of the new facts, and much wit and ingenuity would be required to modify and defend their old positions. Each new invention would violate a greater number of known analogies; for if a theory be required to embrace some false principle, it becomes more visionary in proportion as facts are multiplied, as would be the case if geometers were now required to form an astronomical system on the assumption of the immobility of the earth.

Among other fanciful conjectures concerning the history of Egypt, we may suppose some of the following to be started. "As the banks of the Nile have been so recently colonized for the first time, the curious substances called mummies could never in reality have belonged to men. They may have been generated by some *plastic virtue* residing in the interior of the earth, or they may be abortions of Nature produced by her incipient efforts in the work of creation. For if deformed beings are sometimes born even now, when the scheme of the universe is fully developed, many more may have been 'sent before their time, scarce half made up,' when the planet itself was in the embryo state. But if these notions appear to derogate from the perfection of the Divine attributes, and if these mummies be in all their parts true representations of the human form, may we not refer them to the future rather than the past?—May we not be looking into the womb of Nature, and not her grave? May not these images be like the shades of the unborn in Virgil's Elysium—the archetypes of men not yet called into existence?"

These speculations, if advocated by eloquent writers, would not fail to attract many zealous votaries, for they would relieve men from the painful necessity of renouncing preconceived opinions. Incredible as such skepticism may appear, it has been rivalled by many systems of the sixteenth and seventeenth centuries, and among others by that of the learned Falloppio, who regarded the tusks of fossil elephants as earthly concretions, and the pottery or fragments of vases in the Monte Testaceo, near Rome, as works of nature, and not of art. But when one generation had passed away, and another, not compromised to the support of antiquated dogmas, had succeeded, they would review the evidence afforded by mummies more impartially, and would no longer controvert the preliminary question, that human beings had lived in

Egypt before the nineteenth century: so that when a hundred years perhaps had been lost, the industry and talents of the philosopher would be at last directed to the elucidation of points of real historical importance.

But the above arguments are aimed against one only of many prejudices with which the earlier geologists had to contend. Even when they conceded that the earth had been peopled with animate beings at an earlier period than was at first supposed, they had no conception that the quantity of time bore so great a proportion to the historical era as is now generally conceded. How fatal every error as to the quantity of time must prove to the introduction of rational views concerning the state of things in former ages, may be conceived by supposing the annals of the civil and military transactions of a great nation to be perused under the impression that they occurred in a period of one hundred instead of two thousand years. Such a portion of history would immediately assume the air of a romance; the events would seem devoid of credibility, and inconsistent with the present course of human affairs. A crowd of incidents would follow each other in thick succession. Armies and fleets would appear to be assembled only to be destroyed, and cities built merely to fall in ruins. There would be the most violent transitions from foreign or intestine war to periods of profound peace, and the works effected during the years of disorder or tranquillity would appear alike superhuman in magnitude.

He would study the monuments of the natural world under the influence of a similar infatuation, must draw a no less exaggerated picture of the energy and violence of causes, and must experience the same insurmountable difficulty in reconciling the former and present state of nature. If we could behold in one view all the volcanic cones thrown up in Iceland, Italy, Sicily, and other parts of Europe, during the last five thousand years, and could see the lavas which have flowed during the same period; the dislocations, subsidences, and elevations caused during earthquakes; the lands added to various deltas, or devoured by the sea, together with the effects of devastation by floods, and imagine that all these events had happened in one year, we must form most exalted ideas of the activity of the agents, and the suddenness of the revolutions. Were an equal amount of change to pass before our eyes in the next year, could we avoid the conclusion that some great crisis of nature was at hand? If geologists, therefore, have misinterpreted the signs of a succession of events, so as to conclude that centuries were implied where the characters imported thousands of years, and thousands of years where the language of Nature signified millions, they could not, if they reasoned logically from such false premises, come to any other conclusion than that the system of the natural world had undergone a complete revolution.

We should be warranted in ascribing the erection of the great pyramid to superhuman power, if we were convinced that it was raised in one day; and if we imagine, in the same manner, a continent or mountain-chain to have been elevated during an equally small fraction of the time which was really occupied in upheaving it, we might then be justified in inferring, that the subterranean movements were once far more energetic than in our own times. We know that during one earthquake the coast of Chili may be raised for a hundred miles to the average height of about three feet. A repetition of two thousand shocks, of equal violence, might produce a mountain-chain one hundred miles long, and six thousand feet high. Now, should one or two only of these convulsions happen in a century, it would be consistent with the order of events experienced by the Chilians from the earliest times; but if the whole of them were to occur in the next hundred years, the entire district must be depopulated, scarcely any animals or plants could survive, and the surface would be one confused heap of ruin and desolation. . . .

It may afford, perhaps, a lively illustration of the principle here insisted upon, if I recall to the reader's recollection the legend of the Seven Sleepers. The scene of that popular fable was placed in the two centuries which elapsed between the reign of the emperor Decius and the death of Theodosius the younger. In that interval of time (between the years 249 and 450 of our era) the union of the Roman Empire had been dissolved, and some of its fairest provinces overrun by the barbarians of the north. The seat of Government had passed from Rome to Constantinople, and the throne from a pagan persecutor to a succession of Christian and orthodox princes. The genius of the empire had been humbled in the dust, and the altars of Diana and Hercules were on the point of being transferred to Catholic saints and martyrs. The legend relates, "that when Decius was still persecuting the Christians, seven noble youths of Ephesus concealed themselves in a spacious cavern in the side of an adjacent mountain, where they were doomed to perish by the tyrant, who gave orders that the entrance should be firmly secured with a pile of huge stones. They immediately fell into a deep slumber, which was miraculously prolonged, without injuring the powers of life, during a period of 187 years. At the end of that time the slaves of Adolius, to whom the inheritance of the mountain had descended, removed the stones to supply materials for some rustic edifice: the light of the sun darted into the cavern, and the Seven Sleepers were permitted to awake. After a slumber, as they thought, of a few hours, they were pressed by the calls of hunger, and resolved that Jamblichus, one of their number, should secretly return to the city to purchase bread for the use of his companions. The youth could no longer recognize the once familiar aspect of his native country, and his surprise was increased by the appearance of a large cross triumphantly erected over the principal gate of Ephesus. His singular dress and obsolete language confounded the baker, to whom he offered an ancient medal of Decius as the current coin of the empire; and Jamblichus, on the suspicion of a secret treasure, was dragged before the judge. Their mutual inquiries produced the amazing discovery, that two centuries were almost elapsed since Jamblichus and his friends had escaped from the rage of a pagan tyrant."

This legend was received as authentic throughout the Christian world before the end of the sixth century, and was afterwards introduced by Mahomet as a divine revelation into the Koran, and from hence was adopted and adorned by all the nations from Bengal to Africa who professed the Mahometan faith. Some vestiges even of a similar tradition have been discovered in Scandinavia. "This easy and universal belief," observes the philosophical historian of the Decline and Fall, "so expressive of the sense of mankind, may be ascribed to the genuine merit of the fable itself. We imperceptibly advance from youth to age, without observing the gradual, but incessant, change of human affairs; and even, in our larger experience of history, the imagination is accustomed, by a perpetual series of causes and effects, to unite the most distant revolutions. But if the interval between two memorable eras could be instantly annihilated; if it were possible, after a momentary slumber of two hundred years, to display the new world to the eyes of a spectator who still retained a lively and recent impression of the old, his surprise and his reflections would furnish the pleasing subject of a philosophical romance."

Prejudices Arising from Our Peculiar Position as Inhabitants of the Land.—The sources of prejudice hitherto considered may be deemed peculiar for the most part to the infancy of the science, but others are common to the first cultivators of geology and to ourselves, and are all singularly calculated to produce the same deception, and to strengthen our belief that the course of nature in the earlier ages differed widely from that now established. . . .

The first and greatest difficulty, then, consists in an habitual unconsciousness that our position as observers is essentially unfavorable, when we endeavor to estimate the nature and magnitude of the changes now in progress. In consequence of our inattention to this subject, we are liable to serious mistakes in contrasting the present with former states of the globe. As dwellers on the land, we inhabit about a fourth part of the surface; and that portion is almost exclusively a theatre of decay, and not of reproduction. We know, indeed, that new deposits are annually formed in seas and lakes, and that every year some new igneous rocks are produced in the bowels of the earth, but we cannot watch the progress of their formation; and as they are only present to our minds by the aid of reflection, it requires an effort both of the reason and the imagination to appreciate duly their importance. It is, therefore, not surprising that we estimate very imperfectly the result of operations thus visible to us; and that, when analogous results of former epochs are presented to our inspection, we cannot immediately recognize the analogy. He who has observed the quarrying of stone from a rock, and has seen it shipped for some distant port, and then endeavors to conceive what kind of edifice will be raised by the materials, is in the same predicament as a geologist, who, while he is confined to the land, sees the decomposition of rocks, and the transportation of matter by rivers to the sea, and then endeavors to picture to himself the new strata which Nature is building beneath the waters.

Prejudices Arising from Our Not Seeing Subterranean Changes.—Nor is his position less unfavorable when, beholding a volcanic eruption, he tries to conceive what changes the column of lava has produced, in its passage upwards, on the intersected strata; or what form the melted matter may assume at great depths on cooling; or what may be the extent of the subterranean rivers and reservoirs of liquid matter far beneath the surface. It should, therefore, be remembered, that the task imposed on those who study the earth's history requires no ordinary share of discretion; for we are precluded from collating the corresponding parts of the system of things as it exists now, and as it existed at former periods. If we were inhabitants of another element—if the great ocean were our domain, instead of the narrow limits of the land, our difficulties would be considerably lessened; while, on the other hand, there can be little doubt, although the reader may, perhaps, smile at the bare suggestion of such an idea, that an amphibious being, who should possess our faculties, would still more easily arrive at sound theoretical opinions in geology, since he might behold, on the one hand, the decomposition of rocks in the atmosphere, or the transportation of matter by running water; and, on the other, examine the deposition of sediment in the sea, and the imbedding of animal and vegetable remains in new strata. He might ascertain, by direct observation, the action of a mountain torrent, as well as of a marine current; might compare the products of volcanoes poured out upon the land with those ejected beneath the waters; and might mark, on the one hand, the growth of the forest, and, on the other, that of the coral reef. Yet, even with these advantages, he would be liable to fall into the greatest errors, when endeavoring to reason on rocks of subterranean origin. He would seek in vain, within the sphere of his observation, for any direct analogy to the process of their formation, and would therefore be in danger of attributing them, wherever they are upraised to view, to some "primeval state of nature."

But if we may be allowed so far to indulge the imagination, as to suppose a being entirely confined to the nether world—some "dusky melancholy sprite," like Umbriel, who could "flit on sooty pinions to the central earth," but who was never permitted to "sully the fair face of light," and emerge into the regions of water and of air; and if this being should busy himself in investigating the structure of the globe, he might frame theories the exact converse of those usually adopted by human philosophers. He might infer that the stratified rocks, containing shells and other organic remains, were the oldest of created things, belonging to some original and nascent state of the planet. "Of these masses," he might say, "whether they consist of loose incoherent sand, soft clay, or solid stone, none have been formed in modern times. Every year some part of them are broken and shattered by earthquakes, or melted by volcanic fire; and when they cool down slowly from a state of fusion, they assume a new and more crystalline form, no longer exhibiting that stratified disposition and those curious impressions and fantastic markings, by which they were previously characterized. This process cannot have been carried on for an indefinite time, for in that case all the stratified rocks would long ere this have been fused and crystallized. It is therefore probable that the whole planet once consisted of these mysterious and curiously bedded formations at a time when the volcanic fire had not yet been brought into activity. Since that period there seems to have been a gradual development of heat; and this augmentation we may expect to continue till the whole globe shall be in a state of fluidity and incandescence." . . .

For more than two centuries the shelly strata of the Subapennine hills afforded matter of speculation to the early geologists of Italy, and few of them had any suspicion that similar deposits were then forming in the neighboring sea. . . . Some imagined that the strata, so rich in organic remains, instead of being due to secondary agents, had been so created in the beginning of things, by the fiat of the Almighty. Others, as we have seen, ascribed the imbedded fossil bodies to some plastic power which resided in the earth in the early ages of the world. In what manner were these dogmas at length exploded? The fossil relics were carefully compared with their living analogues, and all doubts as to their organic origin were eventually dispelled. So, also, in regard to the nature of the containing beds of mud, sand, and limestone: those parts of the bottom of the sea were examined where shells are now becoming annually entombed in new deposits. Donati explored the bed of the Adriatic, and found the closest resemblance between the strata there forming, and those which constituted hills above a thousand feet high in various parts of the Italian peninsula. He ascertained by dredging that living testacea were there grouped together in precisely the same manner as were their fossil analogues in the inland strata; and while some of the recent shells of the Adriatic were becoming incrusted with calcareous rock, he observed that others had been newly buried in sand and clay, precisely as fossil shells occur in the Subapennine hills. . . .

In like manner, the volcanic rocks of the Vicentin had been studied in the beginning of the last century; but no geologist suspected, before the time of Arduino, that these were composed of ancient submarine lavas. During many years of controversy, the popular opinion inclined to a belief that basalt and rocks of the same class had been precipitated from a chaotic fluid, or an ocean which rose at successive periods over the continents, charged with the component elements of the rocks in question. Few will now dispute that it would have been difficult to invent a theory more distant from the truth; yet we must cease to wonder that it gained so many proselytes, when we remember that its claims to probability arose partly from the very circumstance of its confirming the assumed want of analogy between geological causes and those now in action. By what train of investigations were geologists induced at length to reject these views, and to assent to the igneous origin of the trappean formations? By an examination of volcanoes now active, and by comparing their structure and the composition of their lavas with the ancient trap-rocks.

The establishment, from time to time, of numerous points of identification, drew at length from geologists a reluctant admission, that there was more correspondence between the condition of the globe at remote eras and now, and more uniformity in the laws which have regulated the changes of its surface, than they at first imagined. If, in this state of the science, they still despaired of reconciling every class of geological phenomena to the operations of ordinary causes, even by straining analogy to the utmost limits of credibility, we might have expected, at least, that the balance of probability would not have been presumed to incline towards the close analogy of the ancient and modern causes. But, after repeated experience of the failure of attempts to speculate on geological monuments, as belonging to a distinct order of things, new sects continued to persevere in the principles adopted by their predecessors. They still began, as each new problem presented itself, whether relating to the animate or inanimate world, to assume an original and dissimilar order of nature; and when at length they approximated, or entirely came around to an opposite opinion, it was always with the feeling, that they were conceding what they had been justified *a priori* in deeming improbable. In a word, the same men who, as natural philosophers, would have been more incredulous respecting any extraordinary deviations from the known course of nature, if reported to have happened *in their own time,* were equally disposed, as geologists, to expect the proofs of such deviations at every period of the past. . . .

I shall now conclude the discussion of a question with which we have been occupied; namely, whether there has been any interruption, from the remotest periods, of one uniform system of change in the animate and inanimate world. We were induced to enter into that inquiry by reflecting how much the progress of opinion in Geology had been influenced by the assumption that the analogy was slight in kind, and still more slight in degree, between the causes which produced the former revolutions of the globe, and those now in every-day operation. It appeared clear that the earlier geologists had not only a scanty acquaintance with existing changes, but were singularly unconscious of the amount of their ignorance. With the presumption naturally inspired by this unconsciousness, they had no hesitation in deciding at once that time could never enable the existing powers of nature to work out changes of great magnitude, still less such important revolutions as those which are brought to light by Geology. They, therefore, felt themselves at liberty to indulge their imaginations in guessing at what *might be,* rather than inquiring *what is;* in other words, they employed themselves in conjecturing what might have been the course of nature at a remote period, rather than in the investigation of what was the course of nature in their own times.

It appeared to them more philosophical to speculate on the possibilities of the past, than patiently to explore the realities of the present; and having invented theories under the influence of such maxims, they were consistently unwilling to test their validity by the criterion of their accordance with the ordinary operations of nature. On the contrary, the claims of each new hypothesis to credibility appeared enhanced by the great contrast, in kind or intensity, of the causes referred to, and those now in operation.

Never was there a dogma more calculated to foster indolence, and to blunt the keen edge of curiosity, than this assumption of the discordance between the ancient and existing causes of change. It produced a state of mind unfavorable in the highest degree to the candid reception of the evidence of those minute but incessant alterations which every part of the earth's surface is undergoing, and by which the conditions of its living inhabitants is continually made to vary. The student, instead of being encouraged with the hope of interpreting the enigmas presented to him in the earth's structure,—instead of being prompted to undertake laborious inquiries into the natural history of the organic world, and the complicated effects of the igneous and aqueous causes now in operation, was taught to despond from the first. Geology, it was affirmed, could never rise to the rank of an exact science,—the greatest number of phenomena must forever remain inexplicable, or only be partially elucidated by ingenious conjectures. Even the mystery which invested the subject was said to constitute one of its principal charms, affording, as it did, full scope to the fancy to indulge in a boundless field of speculation.

The course directly opposed to this method of philosophizing consists in an earnest and patient inquiry, how far geological appearances are reconcilable with the effect of changes now in progress, or which may be in progress in regions inaccessible to us, and of which the reality is attested by volcanoes and subterranean movements. It also endeavors to estimate the aggregate result of ordinary operations multiplied by time, and cherishes a sanguine hope that the resources to be derived from observation and experiment, or from the study of nature such as she now is, are very far from being exhausted. For this reason all theories are rejected which involve the assumption of sudden and violent catastrophes and revolutions of the whole earth, and its inhabitants,—theories which are restrained by no reference to existing analogies, and in which a desire is manifested to cut, rather than patiently to untie, the Gordian knot.

BIBLIOGRAPHY

Chapter XIV—The Scope and Method of Geology

Sir Charles Lyell, *Principles of Geology*. 9th Ed., New York: Appleton, 1860, pp. 1-3, 61-72, 195-196.

George P. Merrill, *Contributions to the History of American Geology*. Report of the U. S. National Museum, 1904, p. 238.

"Verifier," *Scepticism in Geology and the Reasons for It*. London: John Murray, 1878, pp. 72-74, 121-125.

John Woodward, *An Essay Toward a Natural History of the Earth*, 1695.

Internet Archive
Geology from Original Sources
ISBN: B000LEDY4Y
UsedAcceptable
2012-08-03
E1236C4
1